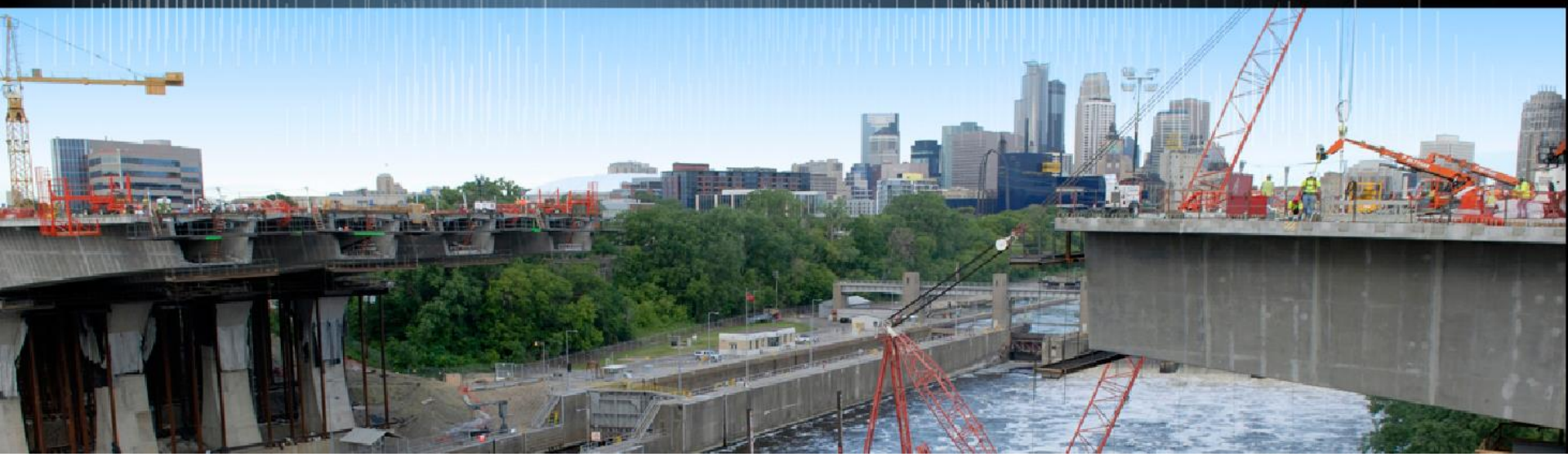
MTS

MTS **CIVIL/STRUCTURAL** SOLUTIONS



# HYBRID SIMULATION RELATED TECHNOLOGIES

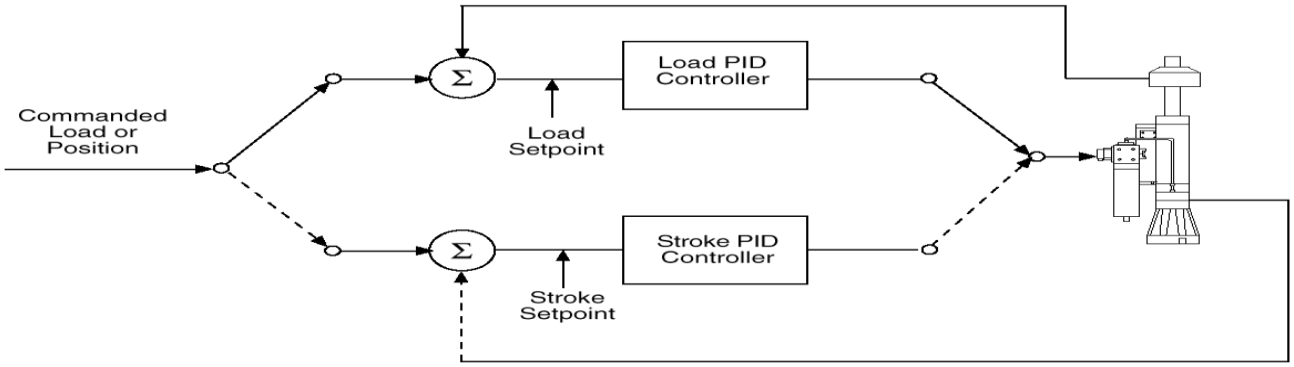
Shawn You, MTS Systems Corporation

be certain.

# Outline

- MTS Calculation Channel Function
  - Motivation
  - Implementation Example
  - Capability and Application
- Virtual Testing Techniques
  - FE Adaptor Element Method
  - MTS Flextest Calculation Channel Approach
  - SIMULINK Modeling Approach
  - Co-Simulation Between SIMULINK and ADAMS
- Generic Element Creation

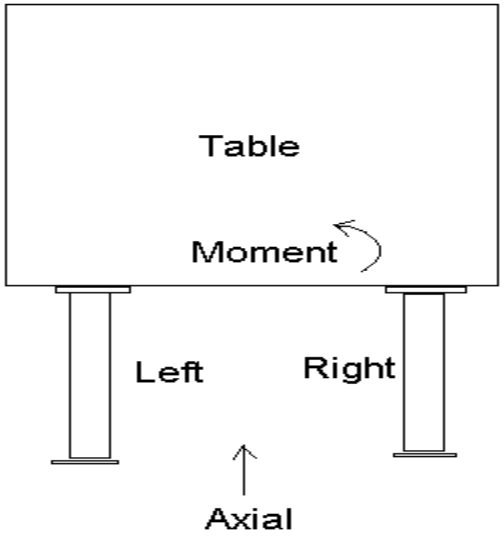
# Regular PID Control




- Feedback signals are from sensors directly
- Load or displacement control

# An Example: Two DOF Control

- Axial and moment control
- Right output = Axial output + 0.5 * Moment output
- Left output = Axial output – 0.5 * Moment output

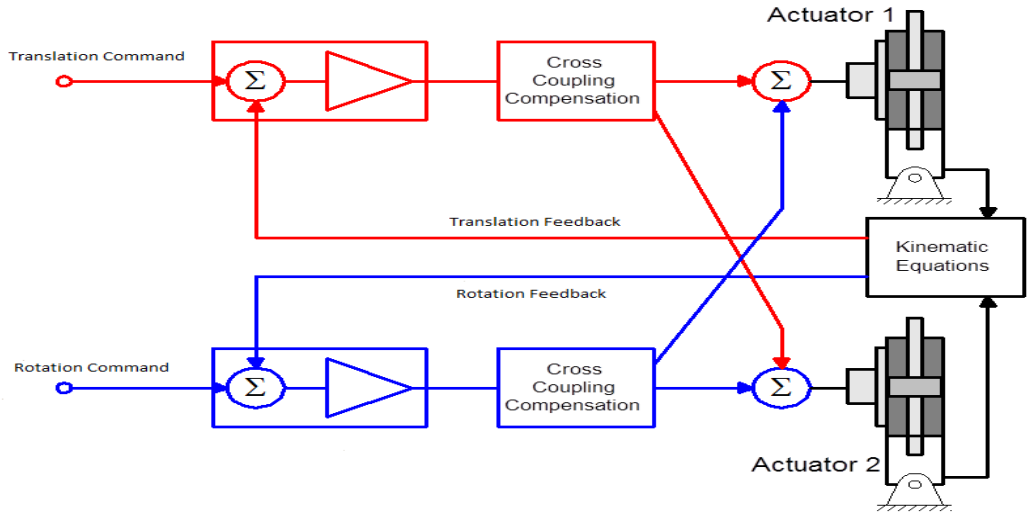



$$M = \begin{bmatrix} 0.5 & 0.5 \\ 1.0 & -1.0 \end{bmatrix}$$

$$\begin{bmatrix} Axial \\ Moment \end{bmatrix} = M * \begin{bmatrix} Right \\ Left \end{bmatrix}$$

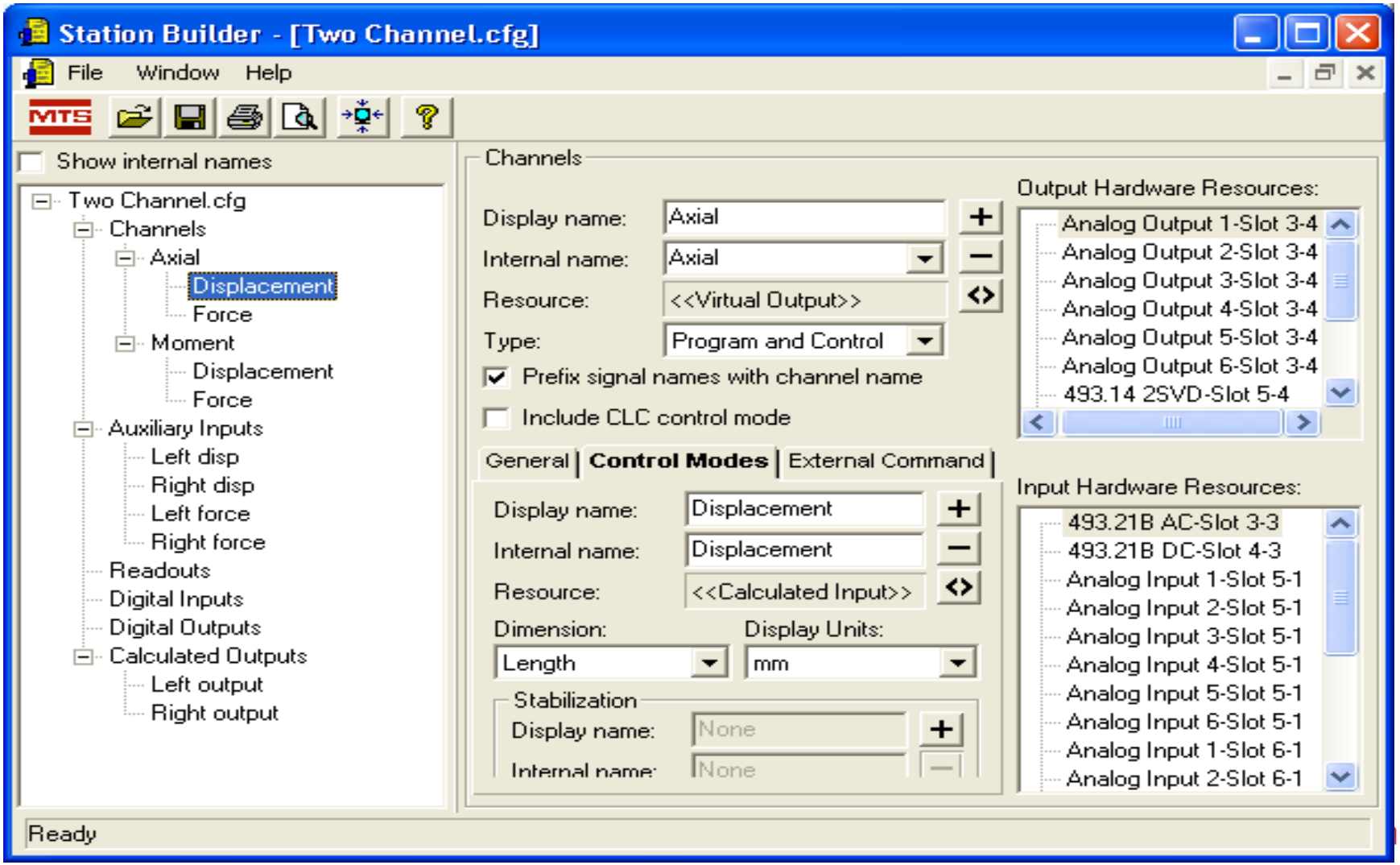
$$\begin{bmatrix} Right \\ Left \end{bmatrix} = M^{-1} * \begin{bmatrix} Axial \\ Moment \end{bmatrix} = \begin{bmatrix} 1.0 & 0.5 \\ 1.0 & -0.5 \end{bmatrix} * \begin{bmatrix} Axial \\ Moment \end{bmatrix}$$

# An Example: Two DOF Control

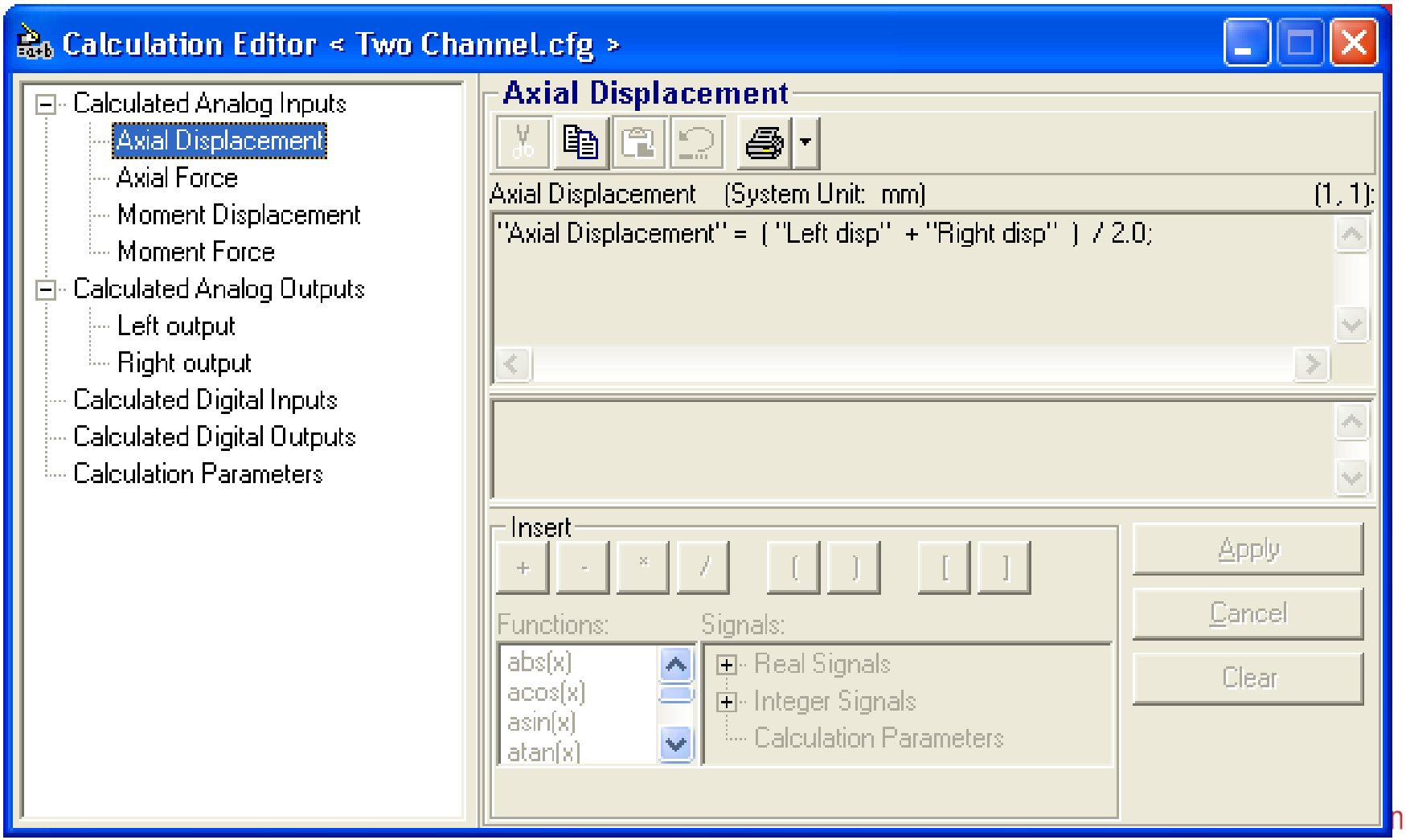



- Commands are in global DOF coordinate system
- Feedbacks are calculated from sensor signals

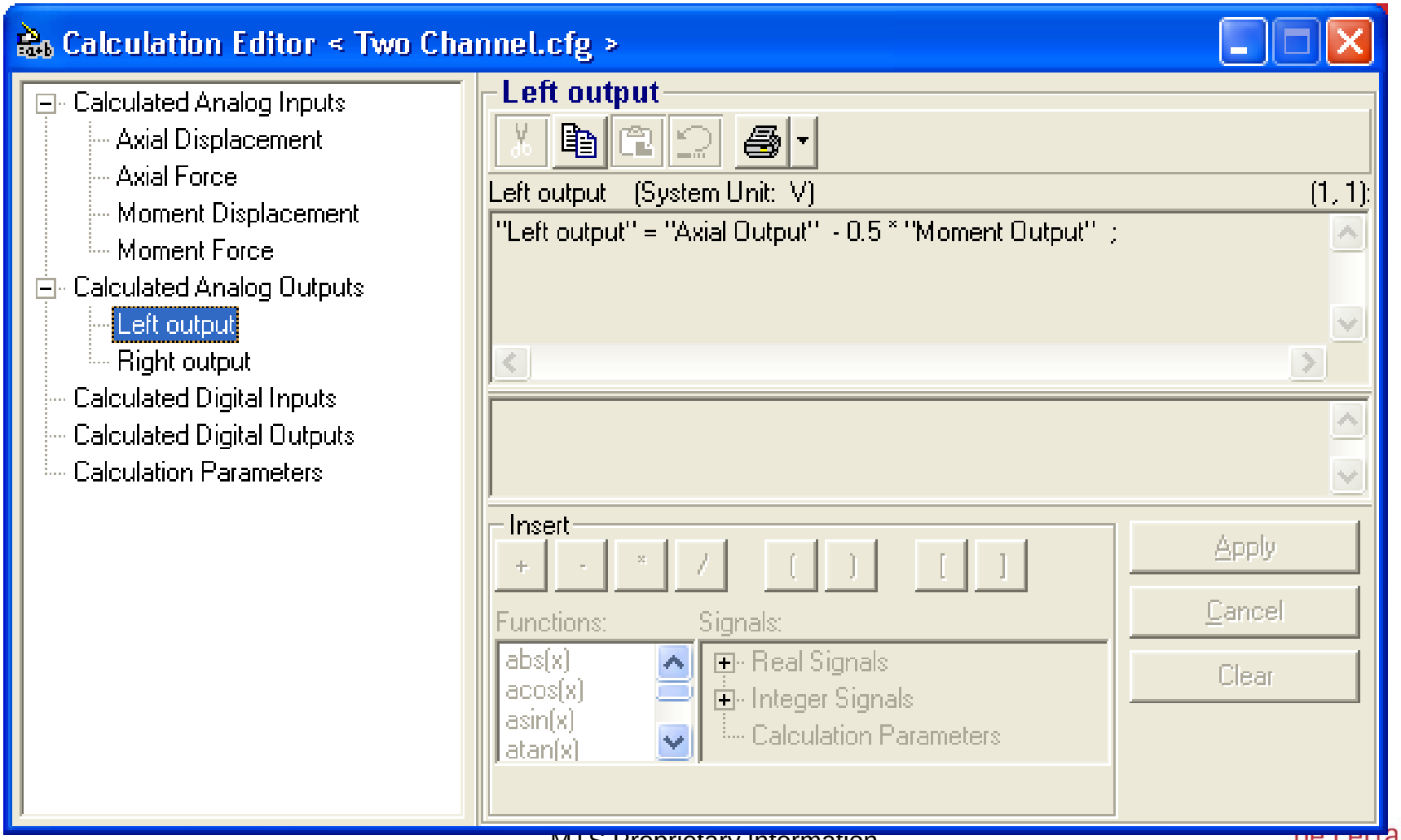
# An Example: Two DOF Control



# An Example: Two DOF Control



# An Example: Two DOF Control



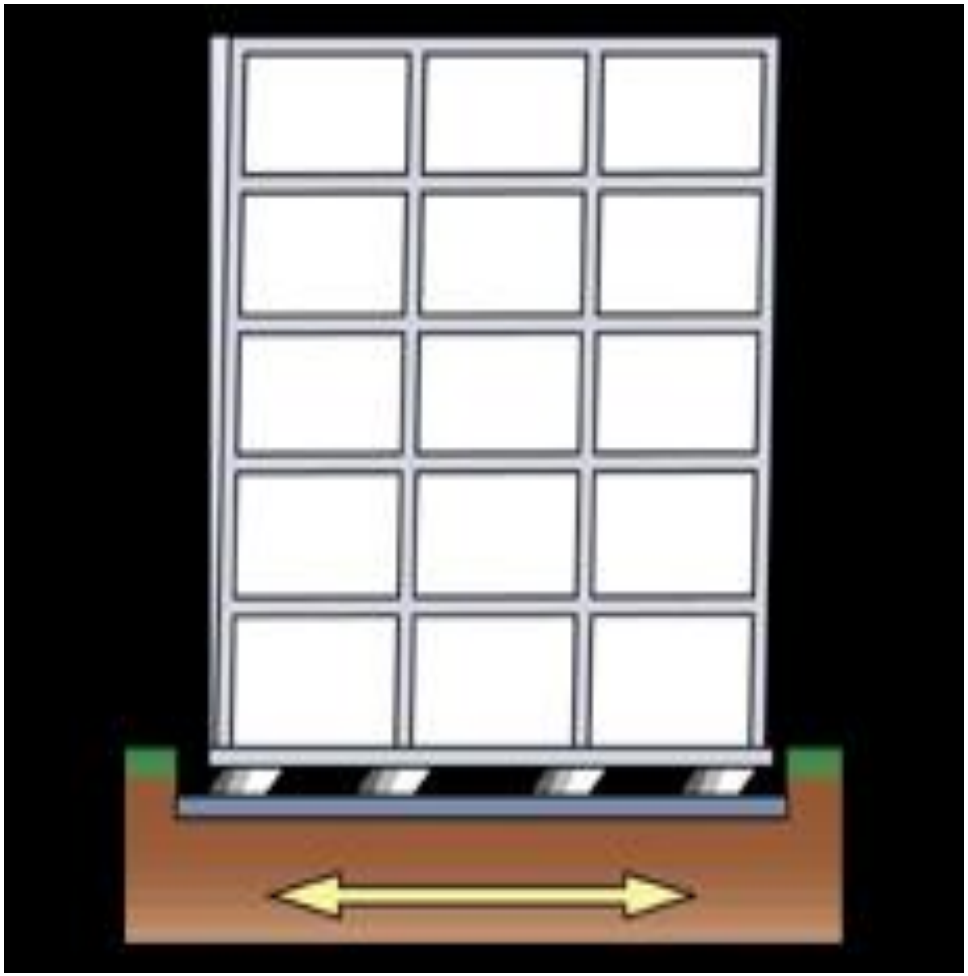
# Use Calculation Channels

- Could involve operations on all digital and analog signals recorded by the controller.
- Calculation code downloaded to the controller when system is loaded. It runs in real-time according to the system clock rate.
- Any function can be written in C can be implemented by calculation channel

# Code for Implementing Explicit Newmark Integration Method – for Hybrid Simulation

```
function int NewmarkExplicitMethod()
{
                    int idof;
                     idof=0;
                    while(idof<ndof)
                    {
                    /* Backup displacement commands and get external force */
                    dcmdz[idof]=dcmd[idof];
                   F[idof]=-(M[idof]*"file generation Command"*"EQSCALE");
                     /* Solve for the CURRENT acceleration and velocity responses. */
                    a[idof]=(F[idof]-R[idof])/M[idof];
                    if(iPsdStep>0)
                    v[idof]=vz[idof]+.5*(az[idof]+a[idof])*Dt;
                  /* Get the NEXT target displacement for the next integratoin step. */
                  dcmd[idof]=d[idof]+v[idof]*Dt+.5*a[idof]*Dt*Dt;
                  /* Update responses. */
                  dz[idof]=d[idof];
                  vz[idof]=v[idof];
                  az[idof]=a[idof];
                  Rz[idof]=R[idof];
                    idof = idof + 1;
  }
```

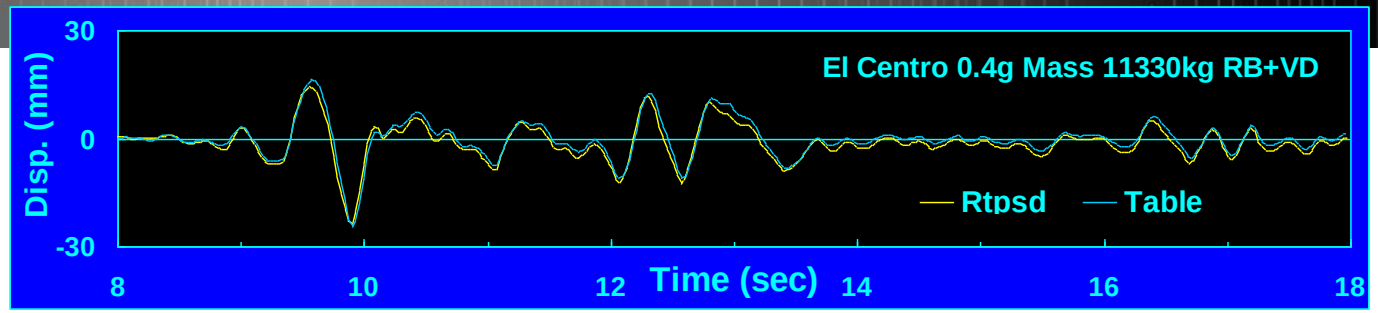
# Bearing Test (at NCREE, Taiwan)

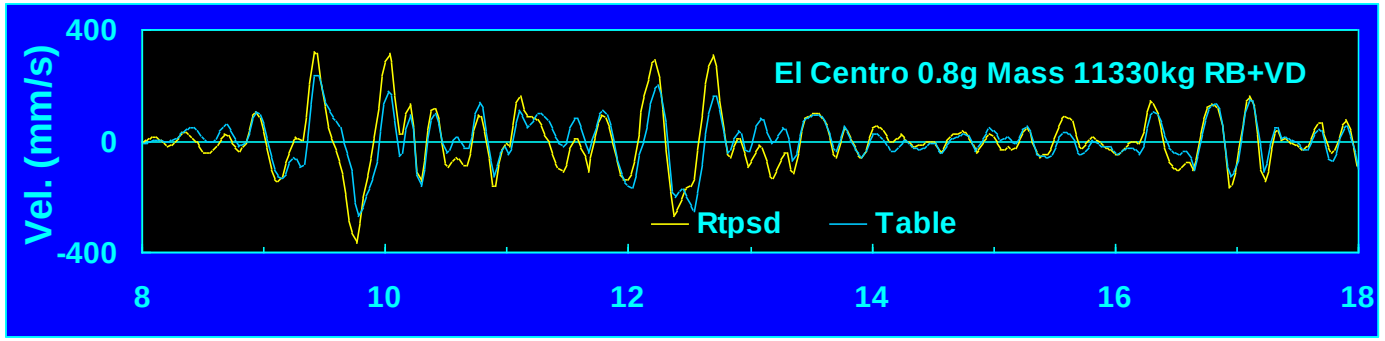


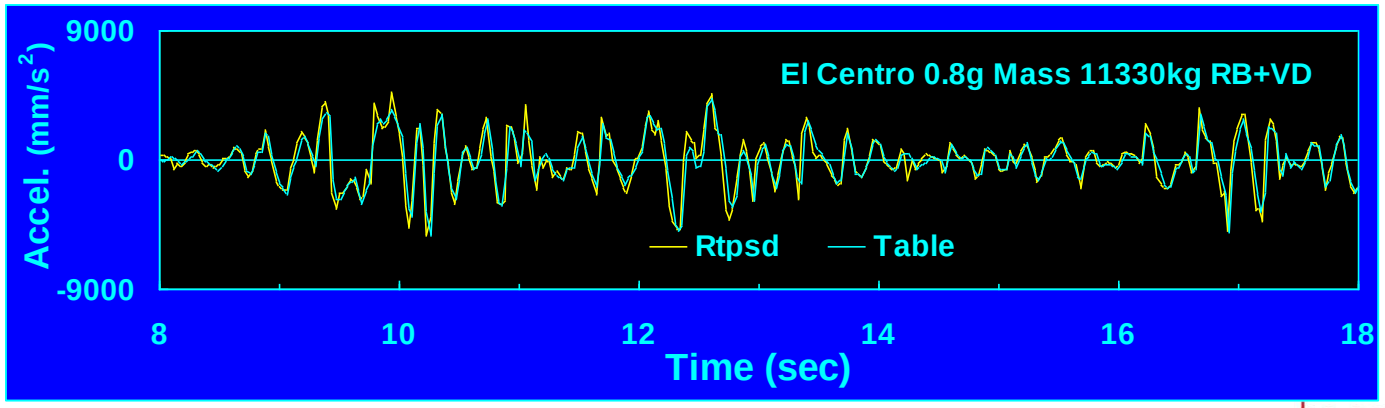
- Model calculates loads on the bearing
- Real-Time hybrid simulation
- Model created using calculation channel

# Shaking Table Tests (at NCREE, Taiwan)

# Hybrid Tests & Shaking Table Tests

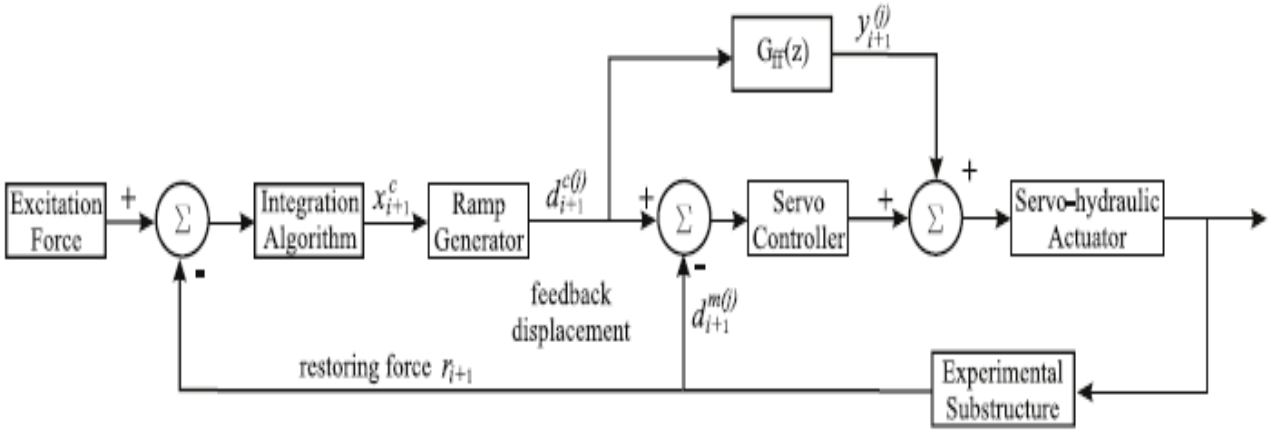


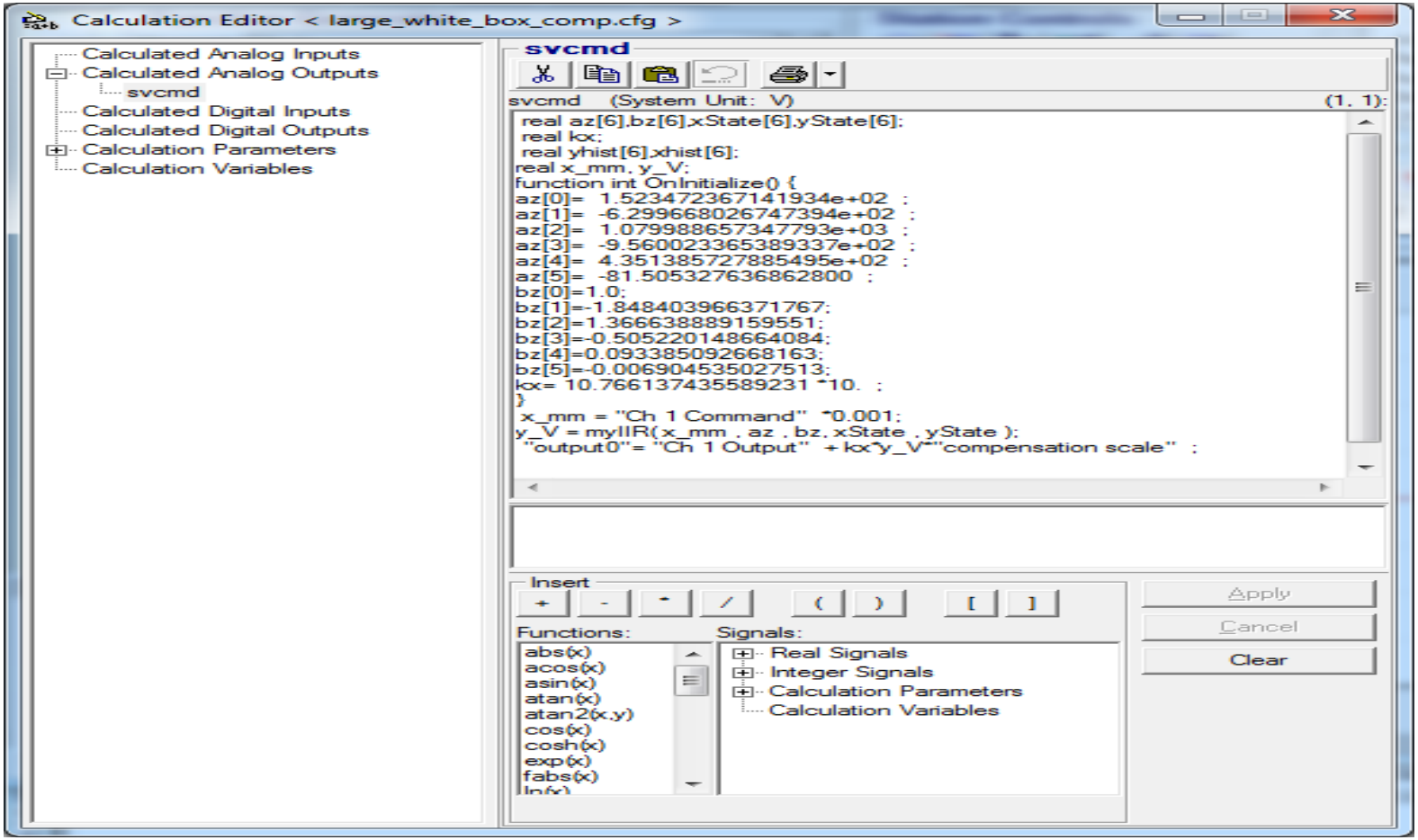
# Roll Off and Delay Compensation

- Hydraulic systems have delay
- Delay causes stability issue
- Real-Time hybrid simulation needs delay compensation

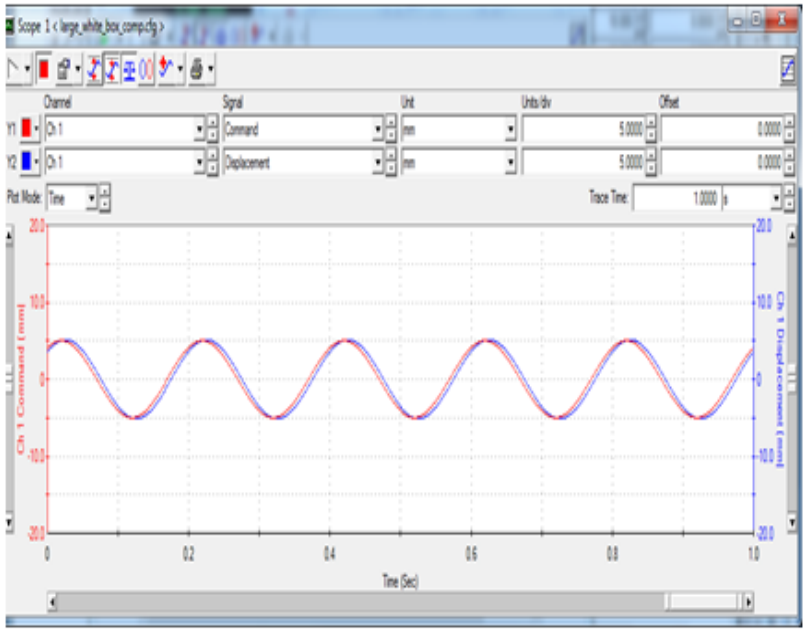



Derivative feedforward compensation

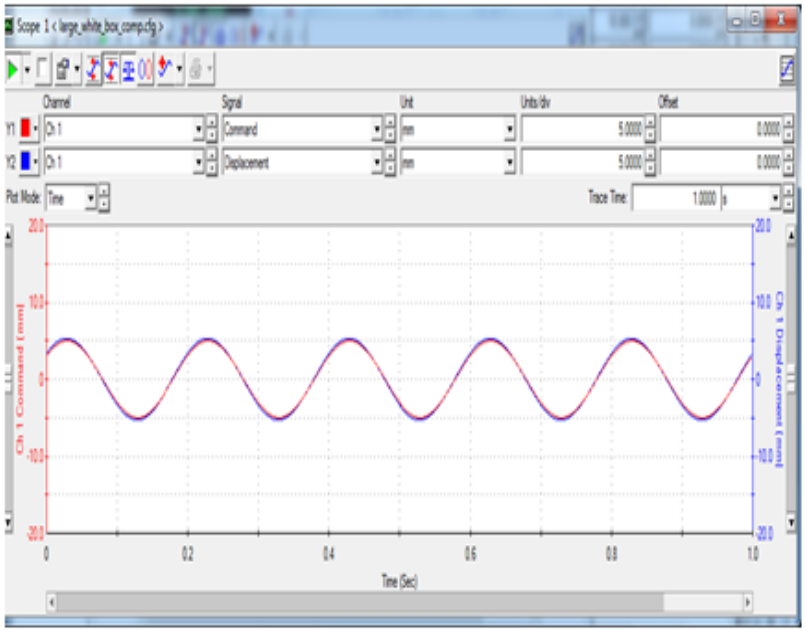
# Roll Off and Delay Compensation



# Roll Off and Delay Compensation




Without delay compensation

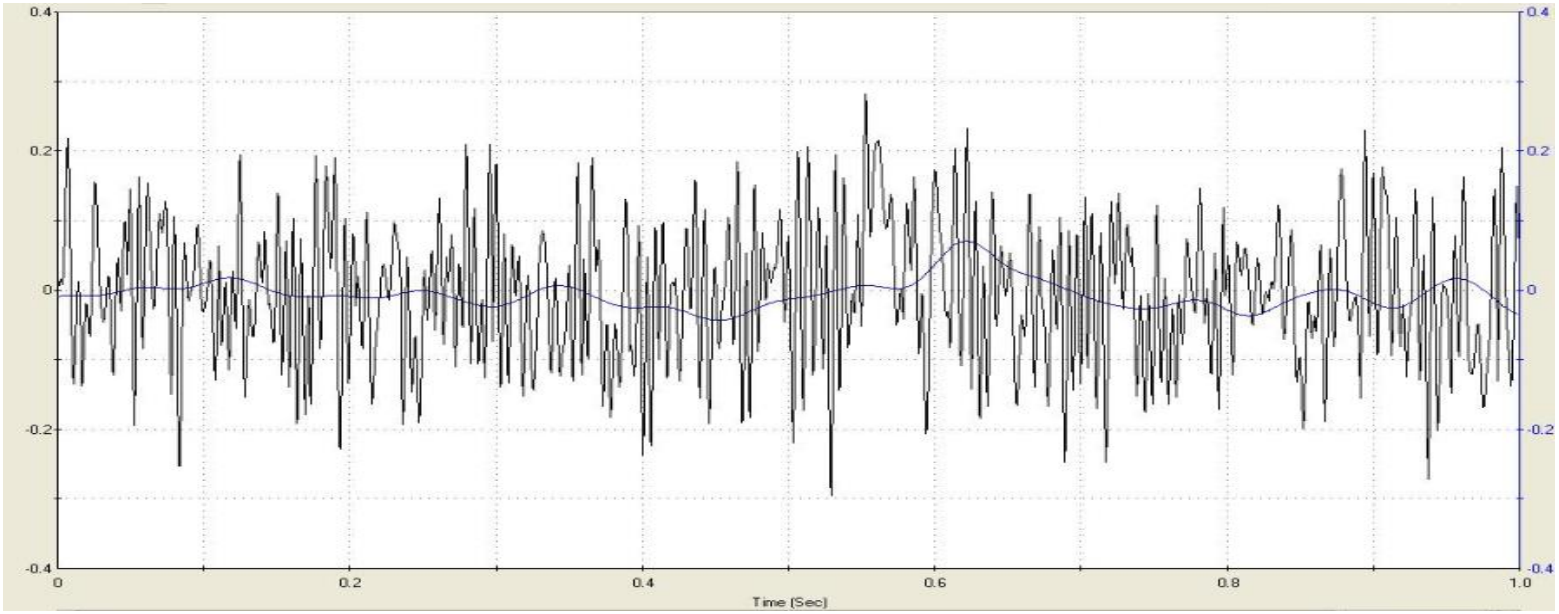



With delay compensation

# Example script for FIR filters

```
int fir[6];
real fPass, fStop, dPass, dStop;
int rsp; int type;
function int OnInitialize() { fPass = 20.0; fStop = 90.0;
dPass = 0.001;
dStop = 0.01;
type = 0;
rsp = FIRLP(fir, 120, fPass, fStop, dPass, dStop);
}
//output0 = rsp/100.0;
output0 = FIR("Left Front Command" , fir);
```

# Noise Elimination



# Conclusions

- Calculation Channel function in MTS Flextest control software provides an effective way to conduct real-time hybrid simulation, conduct delay and roll-off compensation, filter the response signal, setup complicated test configuration, conduct virtual testing, and etc.

- Calculation Channel function only provides a tool. Understanding the physics and come up with correct mathematic calculation is the key for using this method effectively.

# Motivation for Virtual Testing

- Hybrid test could cause damage to specimen and equipment.
- Hybrid test could have convergence and stability issues.
- The test setup could be time consuming and expansive.
- It is important to rehearse the hybrid test before investing time and money to setup the hybrid test.

# FE Adapter Element Method

- Simulation approach that couples two or more displacement-based structural FEA programs together (also referred to as Co-Simulation)
- FEA programs run concurrently and continuously exchanging data at the interfaces of their domains
- This test rehearsal method can be used to simulate both quasi static and real-time hybrid simulations
- Means to verify that the hybrid model has been set up correctly, appropriate analysis parameters have been selected, and all the OpenFresco components have been defined correctly

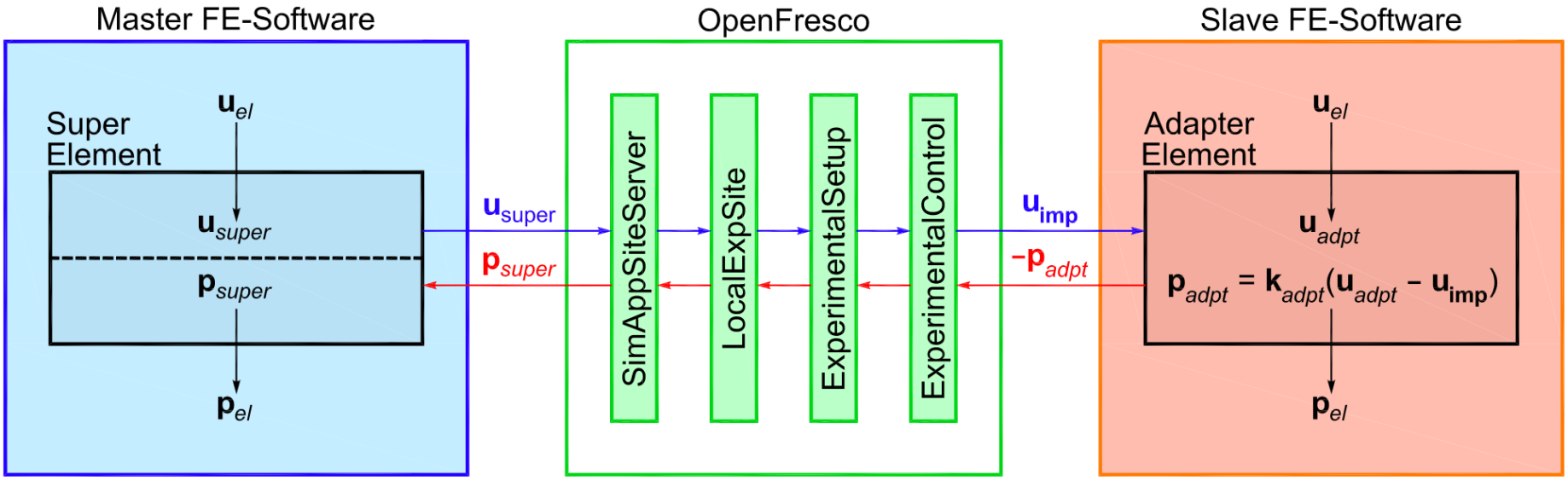
# Concept

- Select one program to act as the master solving the complete hybrid system
- Select remaining programs to act as slaves modeling the different experimental subassemblies
  - Subassemblies act as super-elements
  - Connected to master via interface DOFs
- Generic adapter elements provide interfaces in the slave programs
- Generic super-elements provide interfaces in the master program

# Advantages

- No file system is utilized to exchange data among the different software packages
- Runs continuously and concurrently
- No program-specific modifications need to be made to achieve the coupling
- This means that no access to the entire source-code of a FE-software is required
- A published programming interface (e.g. user-defined elements) is the only requirement

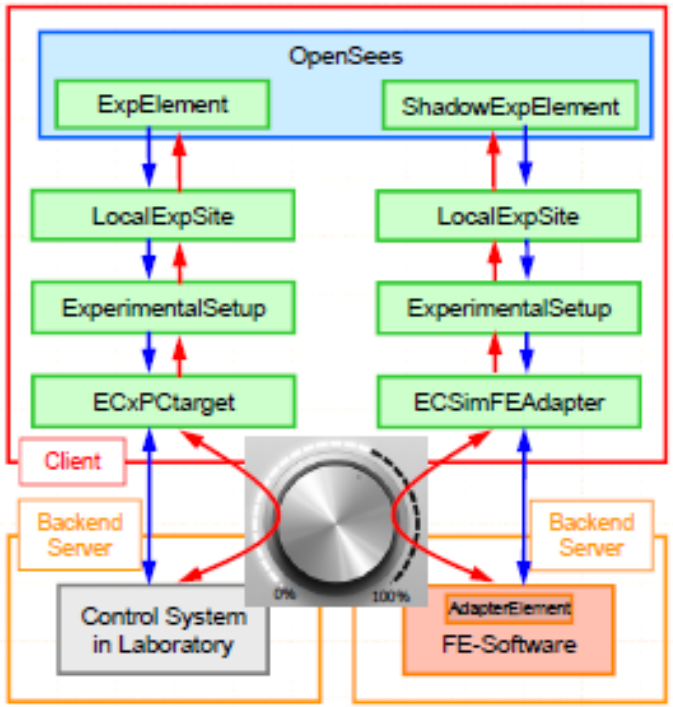
# Implementation Details



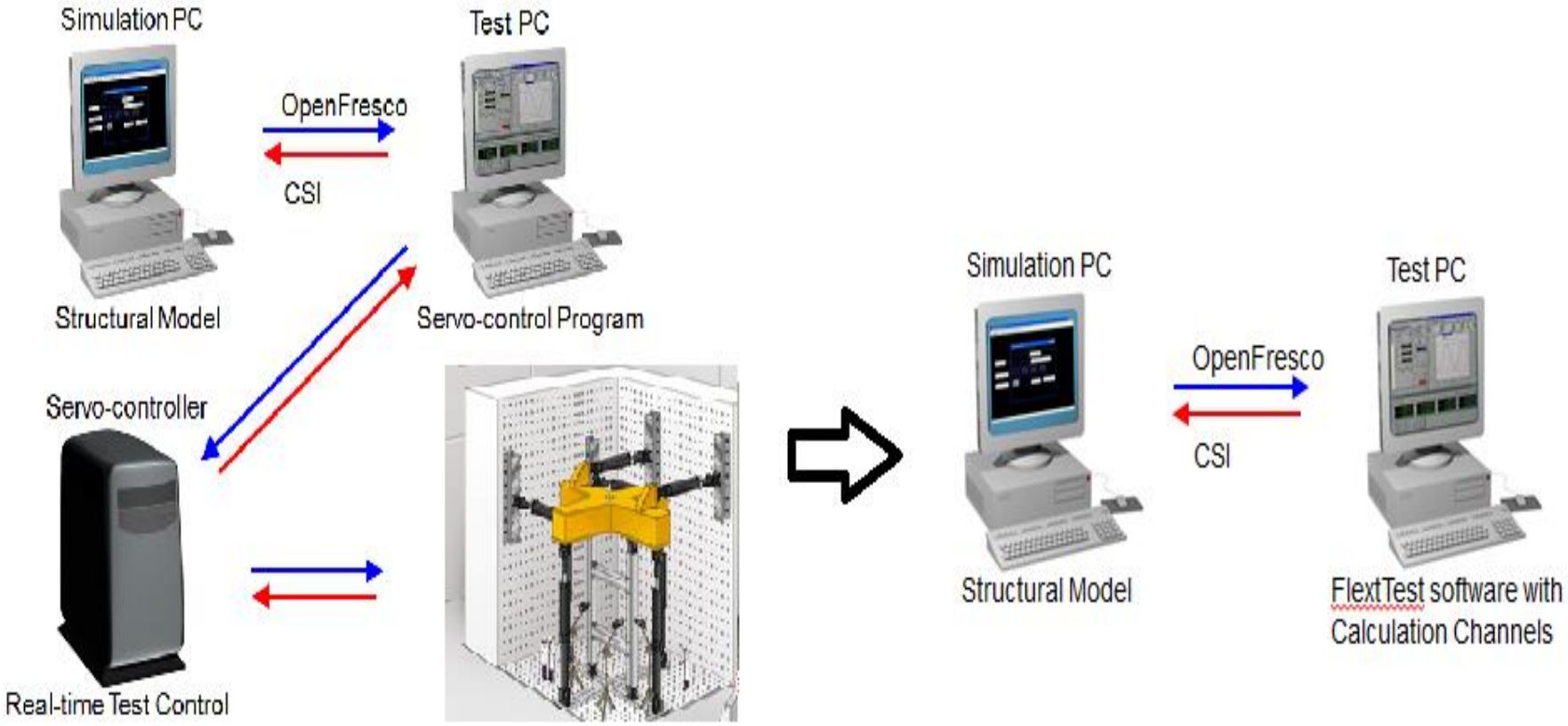

- Both, the super-element in the master FE-software and the adapter element in the slave FE-software need to be once implemented as user-defined elements using the software packages' published programming interfaces
- Adapter and generic elements have been implemented for OpenSees, Abaqus, LS-DYNA, ANSYS, Matlab, and Simulink

# Test Rehearsal

Use FE-Adapter element method to simultaneously connect hybrid model to a numerically simulated test specimen



# Flextest Calculation Channel




» Use calculated signals as control feedback, as auxiliary inputs, as digital inputs/outputs, or to drive output resources such servo valves.

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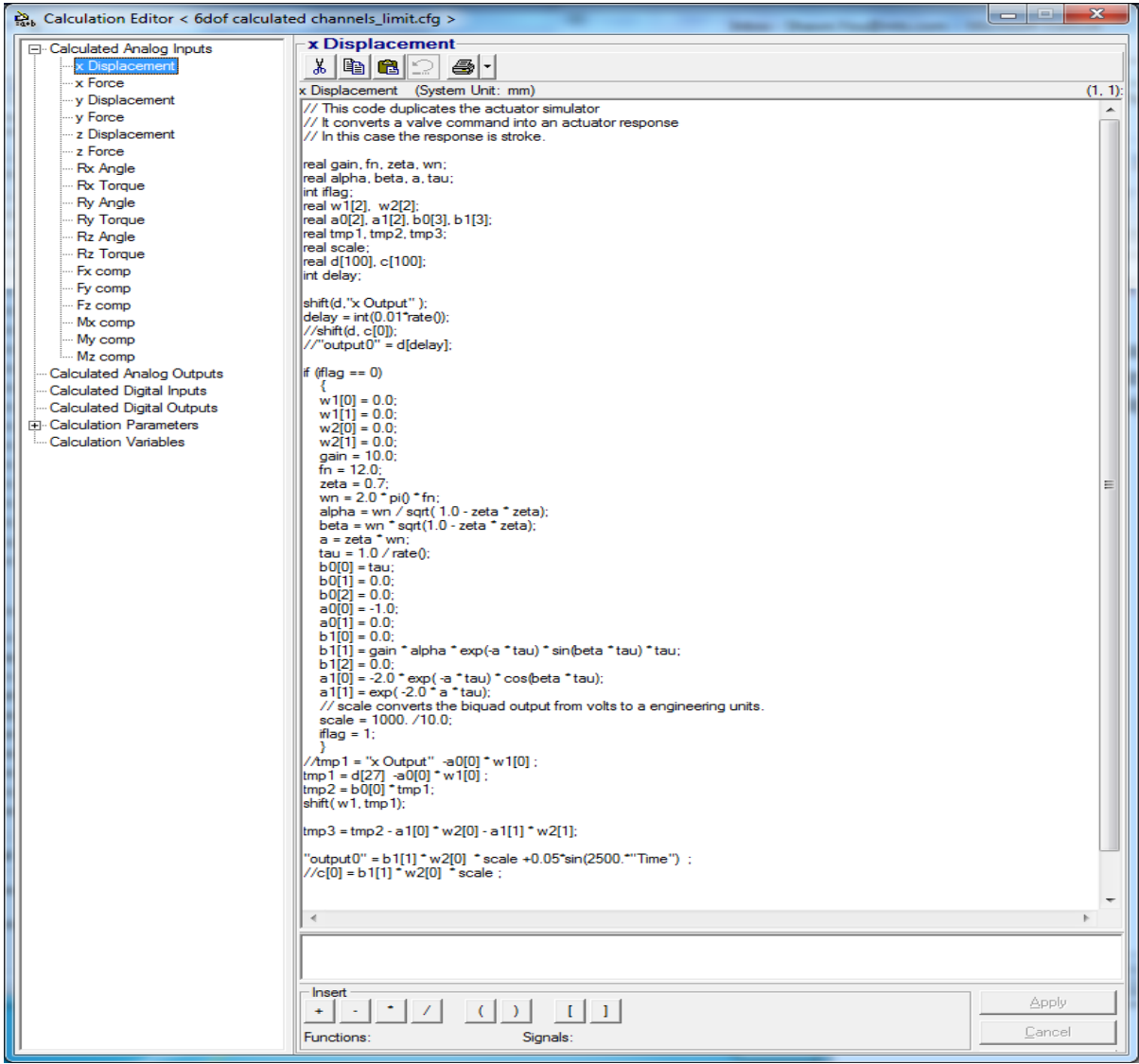
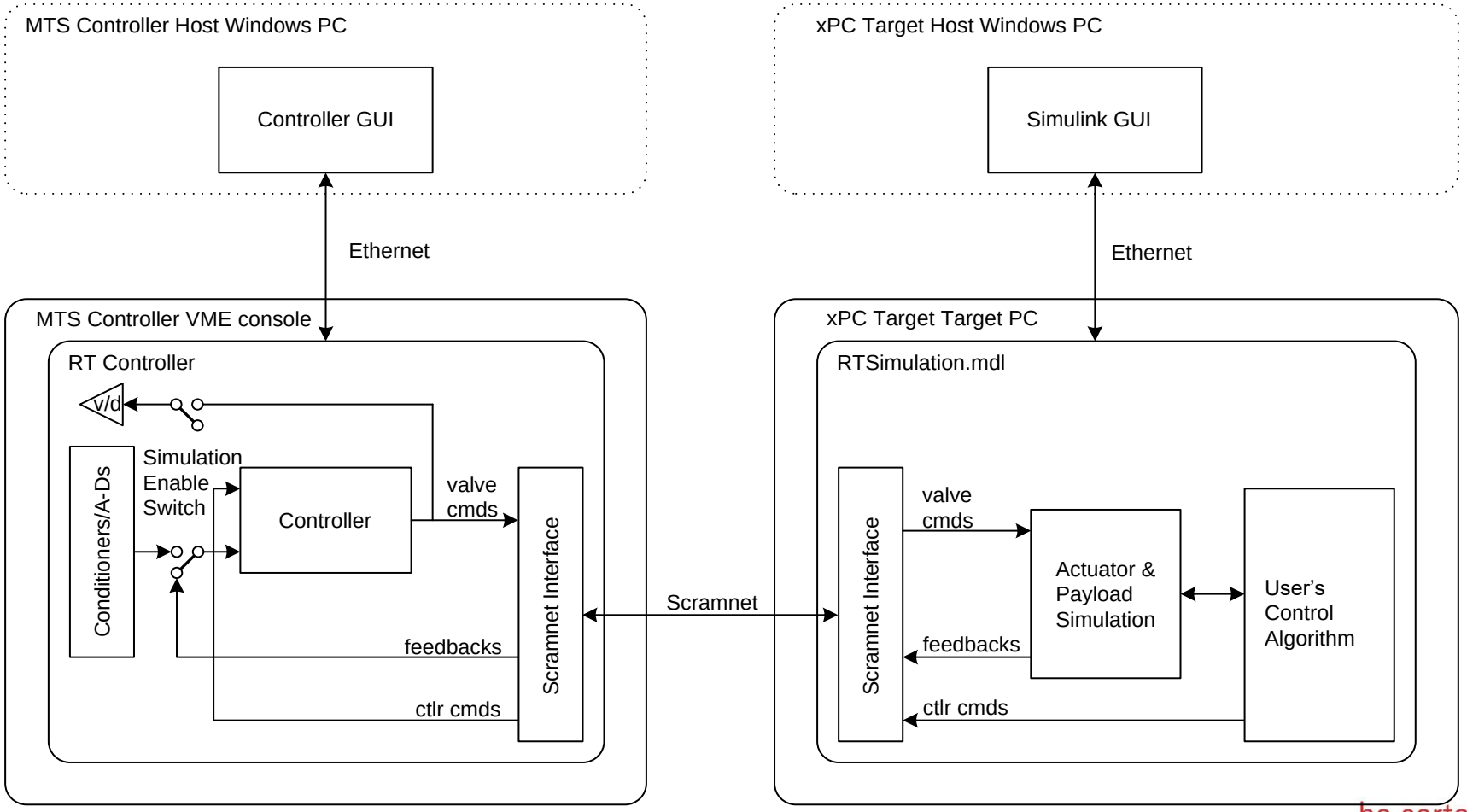
# Hybrid Virtual Testing Example

- Transfer function is implemented to capture system dynamic response including system delay and frequency roll off effect.
- Simulated joint friction and sensor noise.
- Evaluated multiple friction compensation method before the real test.

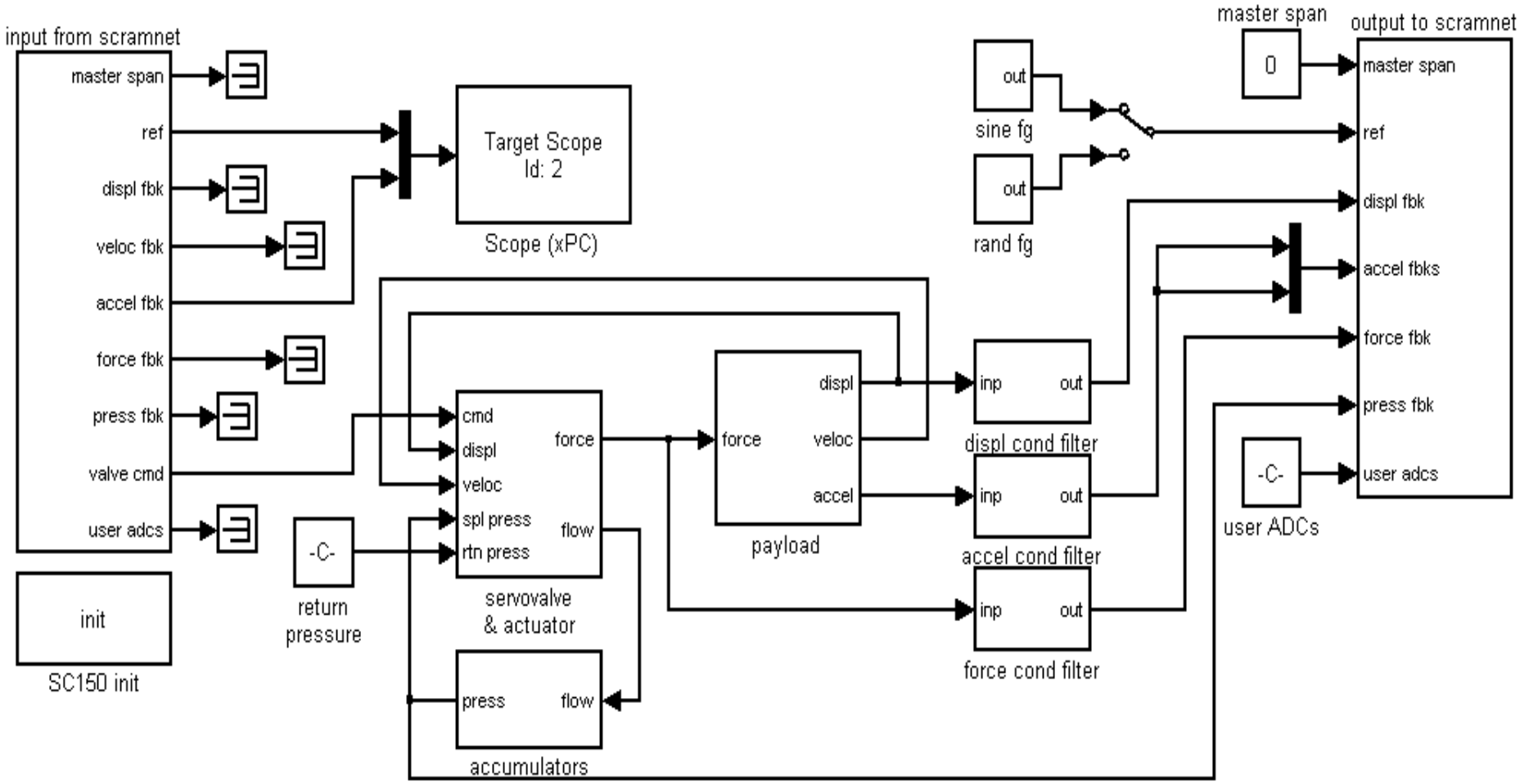


# Test Rehearsal Using Simulink

* Requires all hardware and software components.



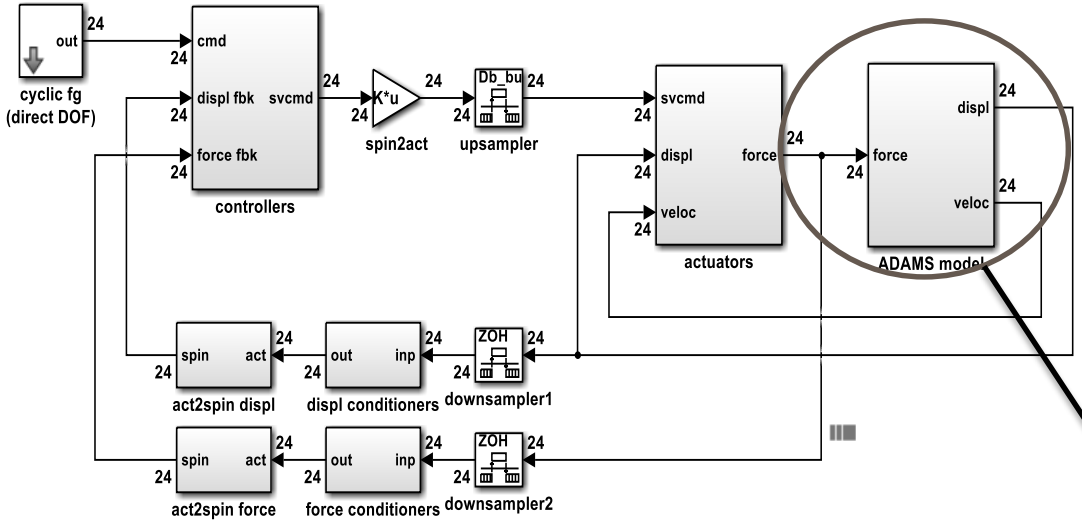
# Real-time Simulation Model

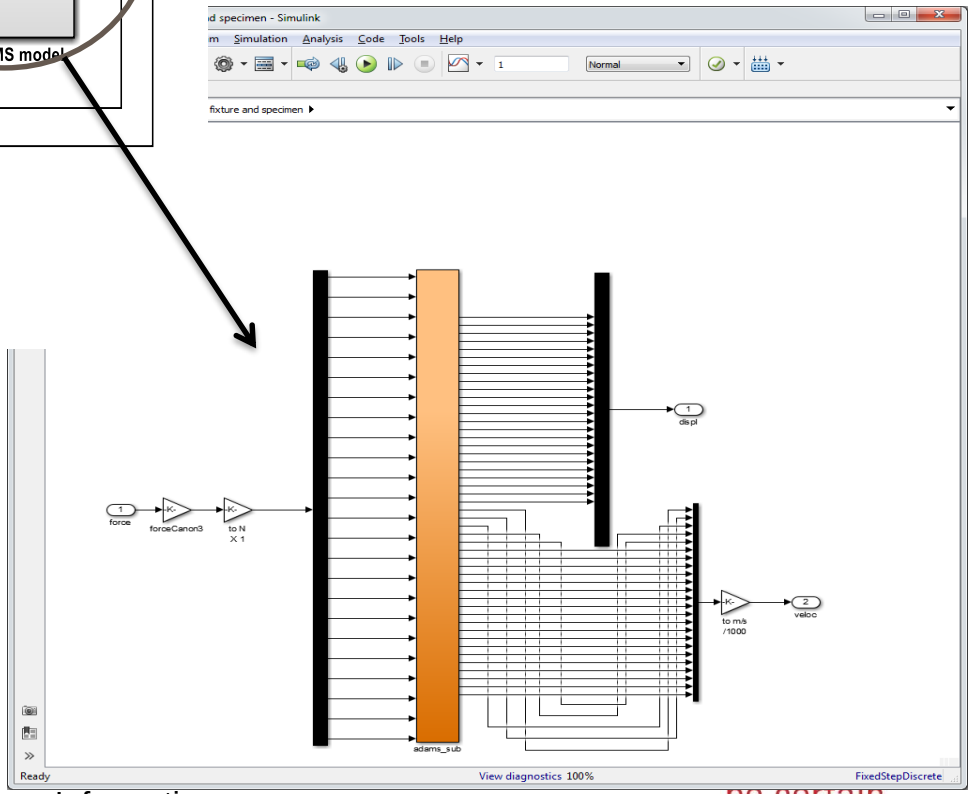


# ADAMS and Simulink Co-Simulation

- ADAMS models mechanical parts, joints, bushings, dampers.
- Simulink models hydraulic elements and controller.
- ADAMS export the plant model to be integrated into Simulink model.
- Simulink model provides actuator forces to ADAMS model.
- ADAMS model provides actuator displacement and velocity based upon the actuator forces provided by the Simulink model.

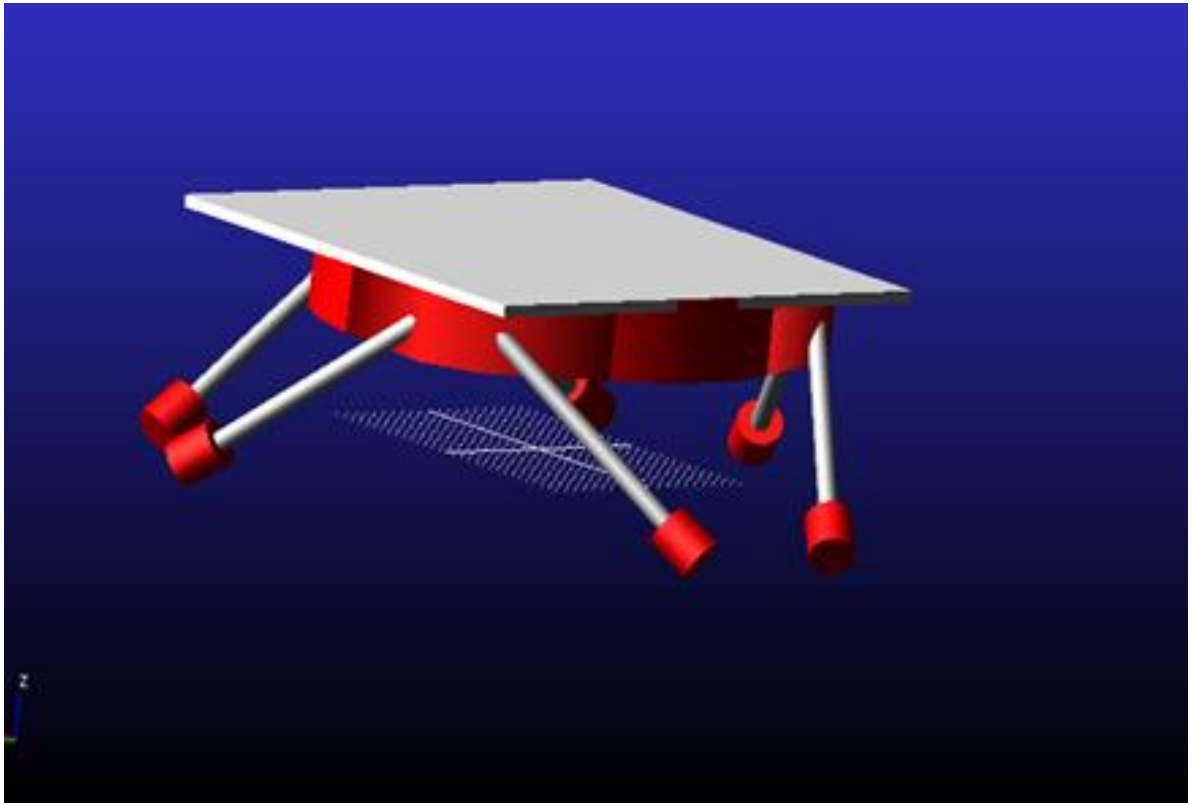
# Integration in Simulink Model



# ADAMS/View Shaker Table Model

- Include all parts and joints
- Parts can be model as flexible in order to simulation resonance accurately



# MTS Quasi Static Hybrid Simulation Solution

Simulation PC

OpenFresco & CSI

Test PC

Structural Model

Servo-control Program

Real-time Test Controller

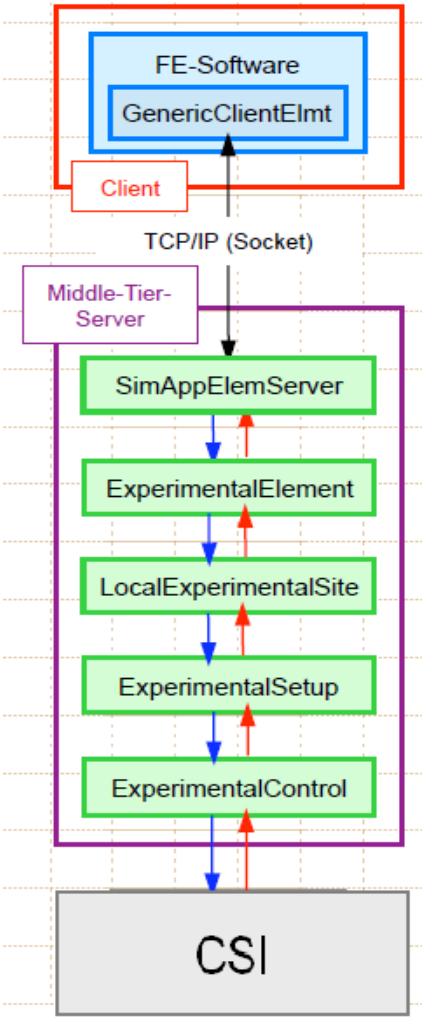
Test Rig

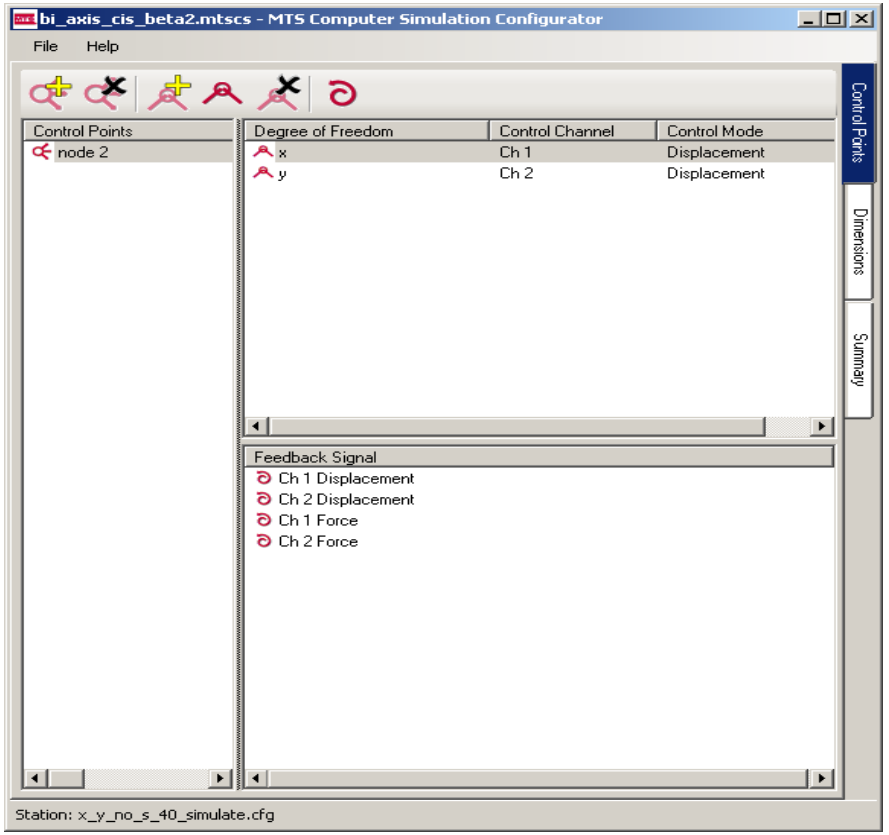
# FEA Software for Simulation Solution

- OpenFresco is independent of FE-software.
- Nearly any software allowing the addition of elements can be used.
- OpenSees, Abaqus, LS-Dyna, Zeus-NL, Matlab, Simulink, and similar programs can in principle be used with OpenFresco.

# Hybrid Simulation Mid-ware

OpenFresco



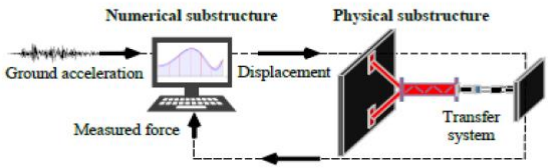



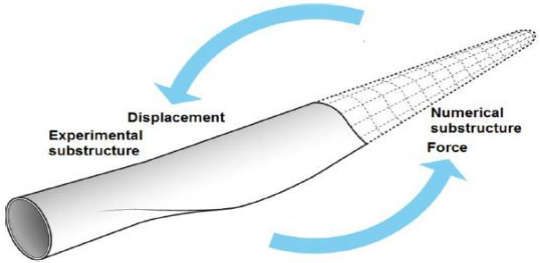

CSI

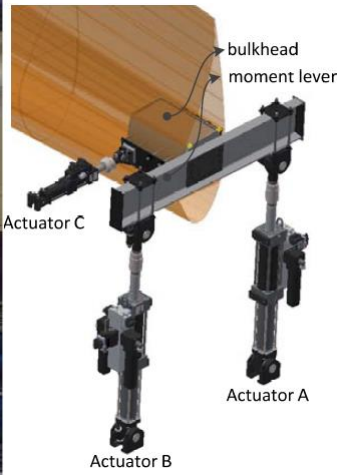
# Hybrid Blade Testing at DTU

## Single Component Hybrid Simulation of a Composite Structure with Multi-Axis Control

ANSYS




ANSYS is the desired finite element analysis software.

# Generic Client Element for ANSYS

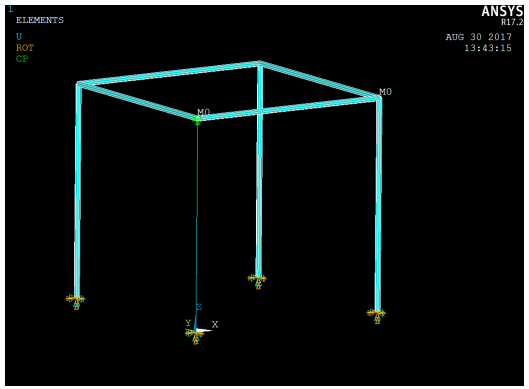
- User-defined element in ANSYS
- Generic Client Element is an interface to OpenFresco
- Has arbitrary number of nodes and degrees of freedom
- Uses TCP sockets for communication
- Makes use of Experimental Elements already in OpenFresco
- Generic Client Element is programmed once for a specific FESoftware

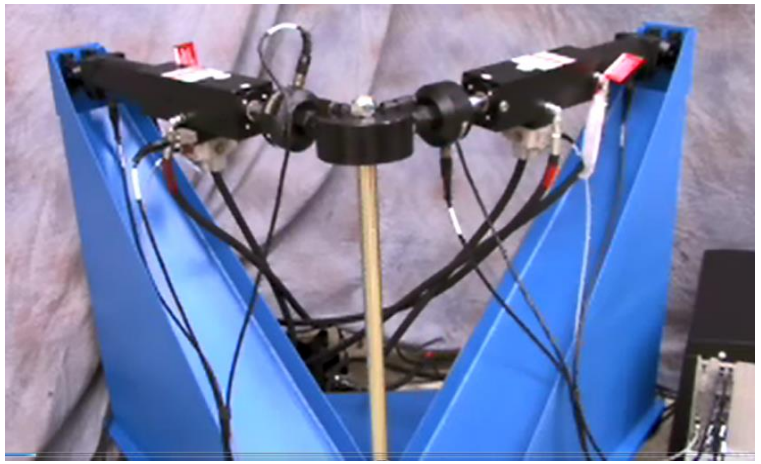
```
c ...    send trial response to experimental site
c
         sData(1) = 3
         do 5, j = 1,4
           sData(1+j) = hsv(i,2+j)
     5   continue
c
         dataTypeSize = sizeDouble
         nleft        = sizeSendData
         call senddata(socketID, dataTypeSize, sData, nleft, stat)
```

# Hybrid Simulation with ANSYS Example

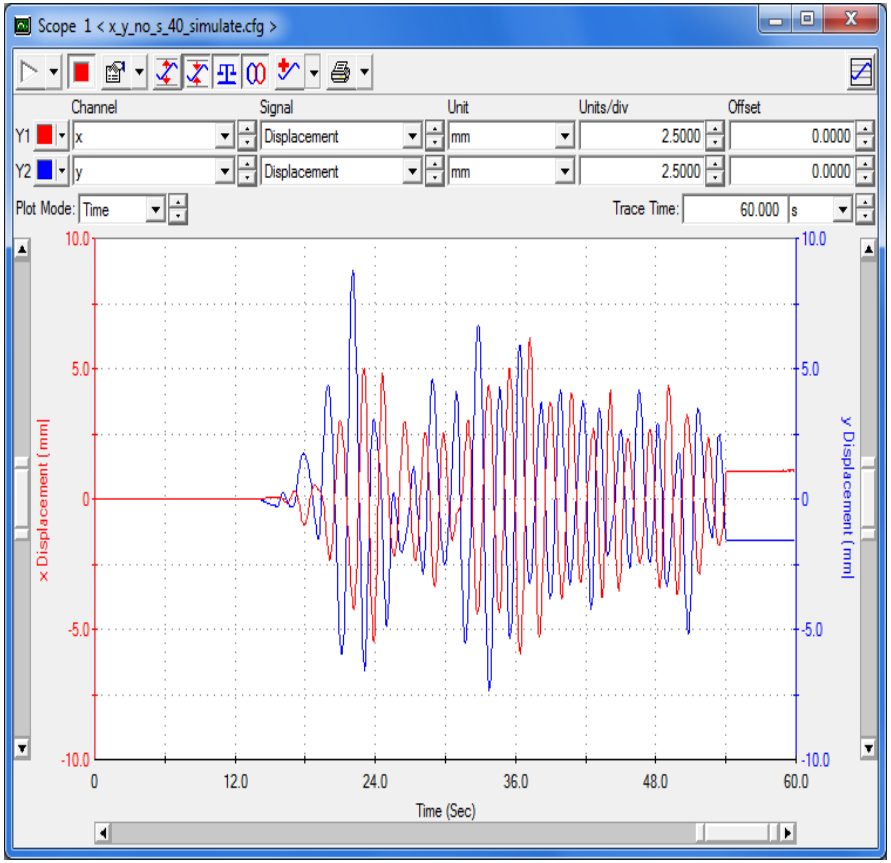
```
!!!!!!!!!!!!!!!!!!define user element
ET,1,USER300                          ! user element
USRDOF,DEFINE,UX,UY
USRELEM,1,2,LINE,1,1,,,,              ! 1 node, NDIM=2
R,1,8090                              ! use real constant to pass tcp port no.

!Assign generic client element
TYPE,1
MAT,
REAL,1
E,2                                   !exp generic element no. 1, use node 2
```

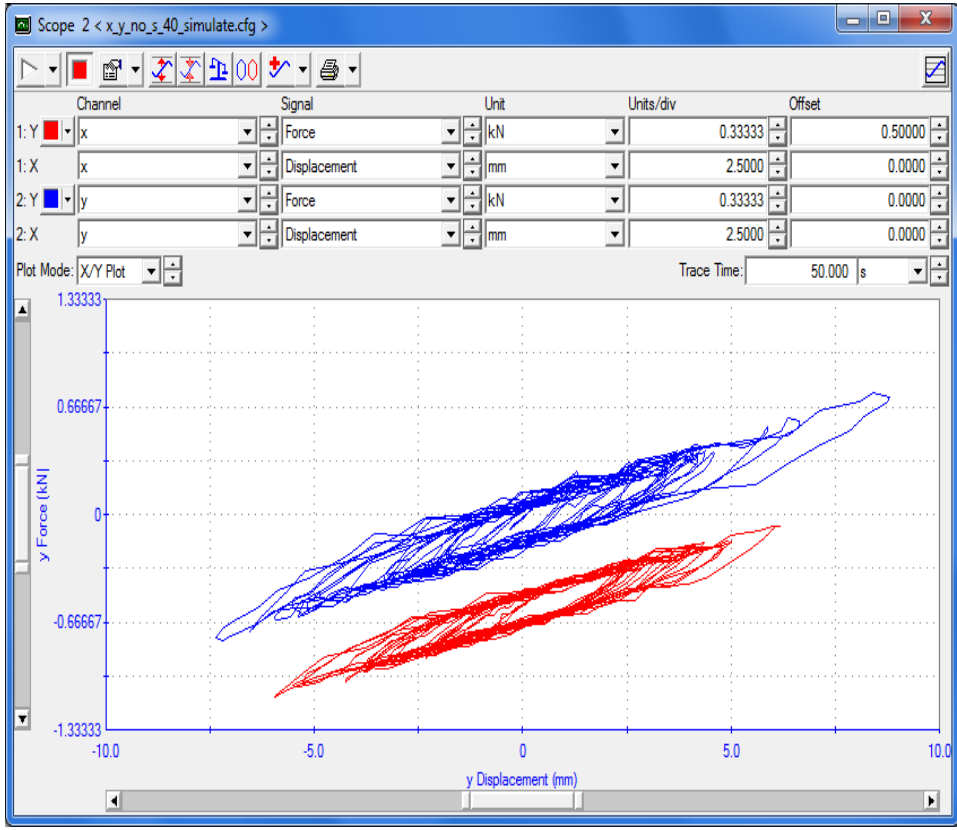


# Hybrid Simulation with ANSYS Example




Actuator Displacements




Displacement vs. Force

# Hybrid Simulation with ANSYS Example

Ansys full transient analysis numerical integration time step: 0.02 sec.
Total simulation time: 10 sec (500 steps)

T1 Total CPU time for main thread (FEA solving time)
T2 Total Ramp Time
T3 Elapsed Time (wall clock time)
T4 Other I/O time (Ansys initialization, write file etc.)

**Table 1: Average Task Execution Time (seconds)**

| Step Ramp Time (sec) | T1 | T2 | T3 | T4 (T3-T1-T2) |
|---|---|---|---|---|
| 0.05 | 10.5 | 25 | 42 | 6.5 |
| 0 | 10.3 | 0 | 17 | 6.7 |

# Conclusion

- It is critical to rehearse hybrid tests to understand the test and prevent damage of the test specimen.
- Co-simulation method can model the specimen using a slave analysis program. Therefore, it can simulate a variety of applications.
- Calculation Channel functionality of the MTS Flextest software can simulate specimen and system behavior. This method does not need additional software or hardware.
- Simulink model can be created to simulate the whole test system.
- Creation of ANSYS generic element enables ANSYS to be connected to OpenFresco and conduct hybrid simulation.