MAL MANUFACTURING AUTOMATION

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Virtual CNC Help File

Contents

0.1 Introduction

Virtual CNC is a comprehensive virtual simulation software package, developed for predicting the performance of a realistic and modular CNC system in a computer simulation environment.

It can be used as a learning tool, as well as an optimization tool for a real CNC system. Furthermore, Virtual CNC assists users in the axis feed drive and controller design.

Virtual CNC has the following features:

· Definition of new 3-Axis and 5-Axis machine.

· Creating tool path or loading a saved tool path file (CL file or APT file.)

· Configuring the trajectory generation including the kinematic profile, interpolation type and smoothing type.

· Flexible ball screw feed drive design and analysis.

· Allow to try out various feed drive design alternatives, control laws and sensors with different resolutions.

· Advanced analysis of frequency analysis, axis tracking error and contour error.

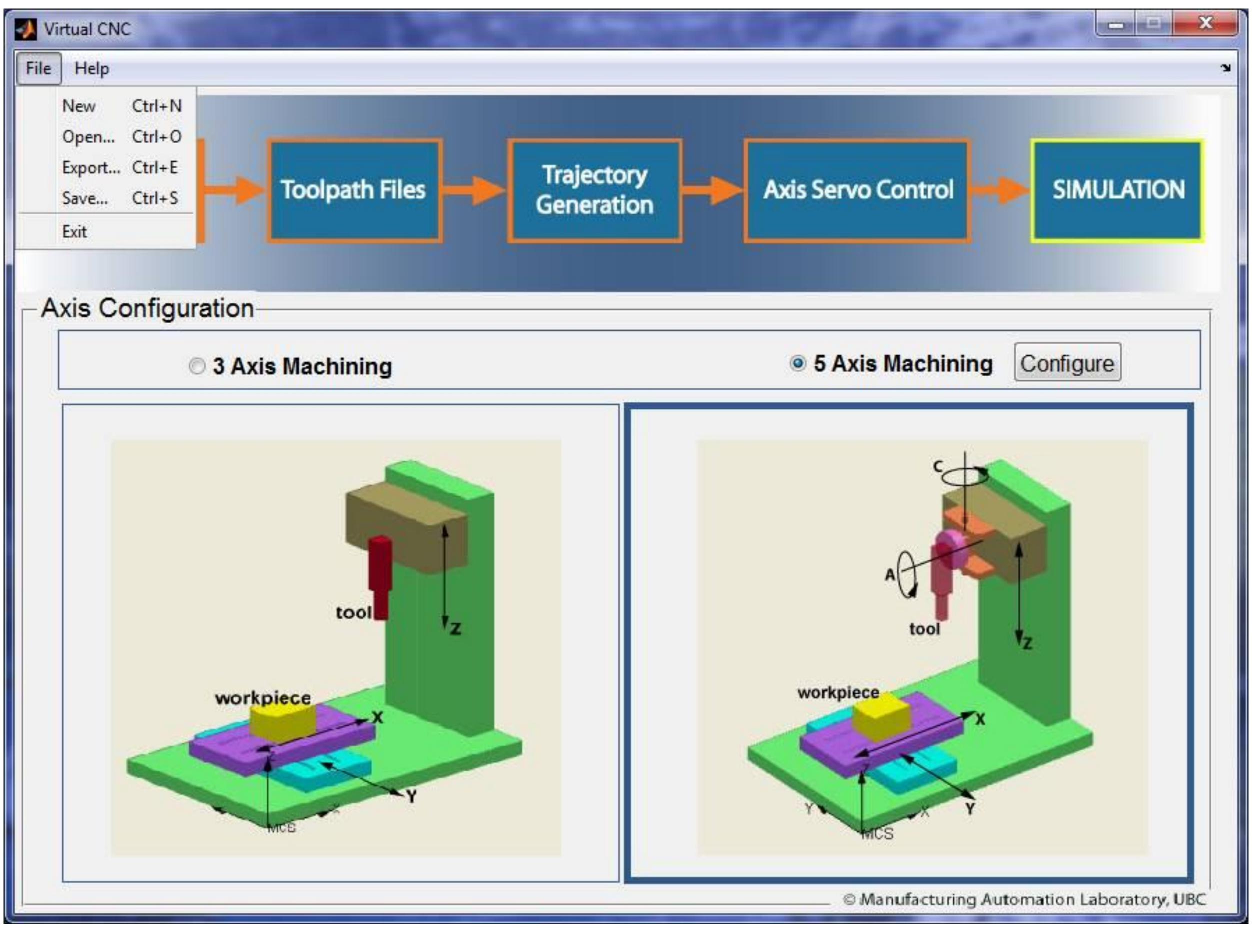
· Allow to export the simulation results including the axis tracking error and contour error.

0.2 Installing and Running Virtual CNC

Run the Virtual CNC installer by double-clicking the VirtualCNCIntallation.exe, and then double-click VCNC.exe to run Virtual CNC.

Loading and Creating Project Files

From the File menu, you can load any of the example files found in the examples folder VCNC/Virtual CNC Examples, or can create a new project.



0.3 Example Files

The following example files are provided with Virtual CNC. They can be found in the **Virtual CNC Examples** Directory under your main **VCNC** directory.

To open an example file, select **File > Open** in the main Virtual CNC window. The examples are included within the VCNC/Virtual CNC Examples folder and are divided into four subfolders:

Ex01_Kinematic Configurations: Two examples for kinematic configurations.

The example project **Ex01A_3 Axis Rigid Drive Example.vcnc** is configured X axis, Y axis and Z axis feed drive as the lead screw rigid drive.

The example project **Ex01B_5 Axis Rigid Drive Example.vcnc** is configured the X axis, Y axis and Z axis feed drive as the lead screw rigid drive, and configured B axis and C axis feed drive as the rotary drive.

Ex02_Flexible Ball Screw Drive Systems: An example for flexible ball screw drive systems.

The example project **Ex02_Flexible Ball Screw Drive Systems.vcnc** is configured X axis, Y axis feed drive as the flexible ball screw and Z axis feed drive as the lead screw rigid drive. The result shows that the flexible ball screw feed drives have vibrations.

Ex03_Active Damping of Drives: Two examples for active damping of drives.

These projects are based on the example project **Ex02_Flexible Ball Screw Drive Systems.vcnc** and implement two methods to actively dampen vibrations occurring in flexible ball screw feed drives: input shaping and accelerometric feedback.

The example project **Ex03A_Input Shaping .vcnc** applies input shaping within the trajectory generation module.

The example project**Ex03B_Accelerometric Feedback.vcnc** uses active damping within the P-PI controller.

Ex04_Trajectory Generation with Splines: Two examples for configuring the trajectory generation with splines.

These example projects are named**Ex04A_3Axis_Trajectory Generation with Splines_Optimized Feedrate.vcnc**,
and **Ex04B_5Axis_Trajectory Generation with Splines_Optimized Feedrate.vcnc**, and optimize the feed rate profile when generating the trajectory path, for 3-axis and 5-axis configurations respectively.

1.0 User Manual

1.1 Overview of Virtual CNC

Virtual CNC could predict the performance of a realistic and modular CNC system in a computer simulation environment. But before the simulation you should configure the trajectory generation, axis feed drive, controller and so on.

Virtual CNC has five modules to simulate: Axis Configuration, Toolpath File, Trajectory Generation, Axis Servo Control, and Simulation.

Axis Configuration: In Axis Configuration Module, you can build and configure a 3-Axis or 5-Axis machine structure and check the feasibility.

Toolpath File: In Toolpath File Module, you should create or load a toolpath file as the reference toolpath file.

Trajectory Generation: In Trajectory Generation Module, you should select the trajectory requirements, which include constant, trapezoidal, cubic acceleration and optimized feedrate profiles. The interpolation type also has two options: point to point and continuous interpolation.

Axis Servo Control: In Axis Servo Control Module, you can configure the feed drive, controller, feedback and disturbance based on your own axis servo drive and control law.

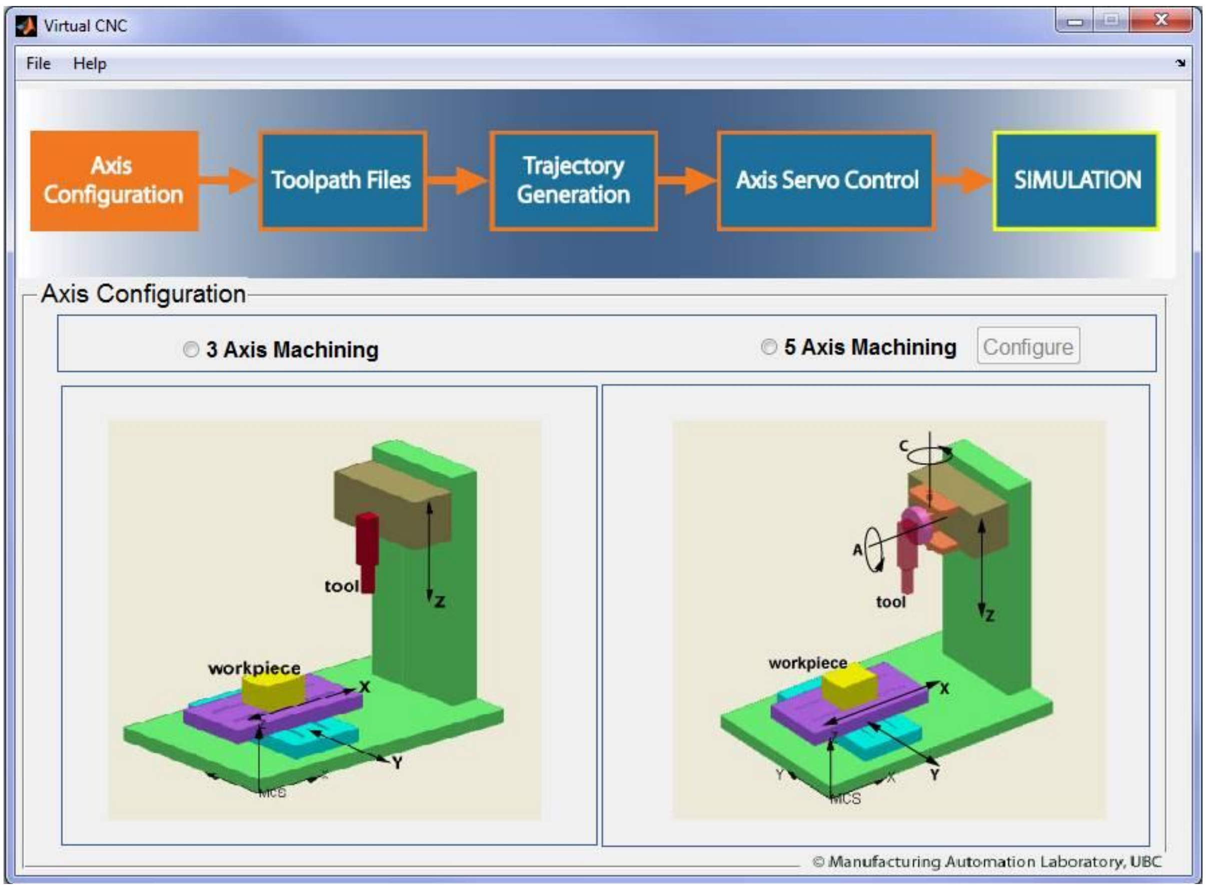
Simulation: You'll get the simulated results including actual toolpath, tracking error and contouring error by running simulation. In the advanced analysis toolbox, you also can analyze the frequency response, axis tracking and contouring.

1.2 Axis Configuration

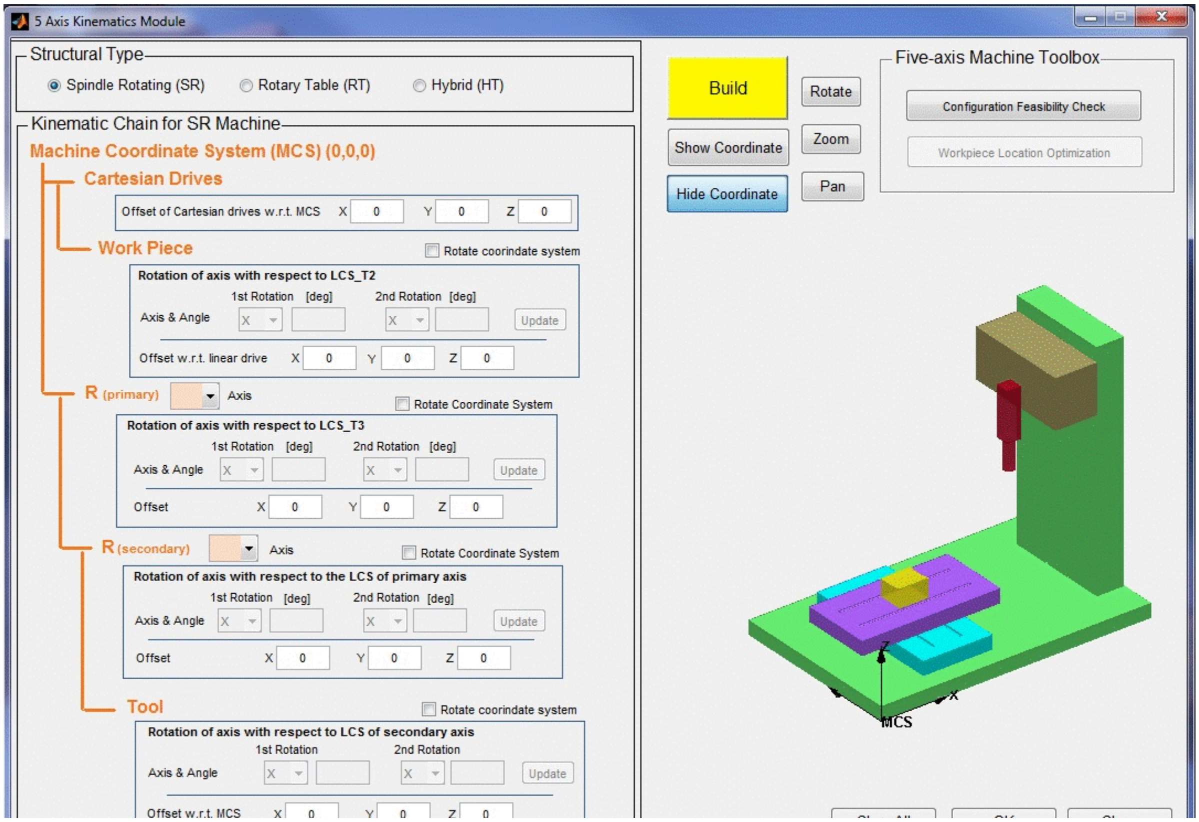
The Axis Configuration module has two options: 3 Axis Machining and 5 Axis Machining.

Nothing needs to be configured for 3 axis machine.

In the 5-Axis Machine Configuration Module, you'll configure and build the kinematical structure of a machine tool for your CNC system and check if the machine structure configuration is feasible.



To configure a 5 axis machine, select the 5 Axis Machining radial button first, and then click the Configure button to open the 5 Axis kinematics Module configuration interface.



The 5 Axis machine must be configured with the following five steps.

Step 1: Selecting the Structural Type

There are three options for the structure type: Spindle Rotating (SR), Rotary Table (RT) and Hybrid (HT).

- With the Spindle Rotating (SR) structure, both rotary axes are built on to the spindle part so the orientation motion is driven by the spindle;
- With the Rotary Table (RT) structure, both rotary axes are built on to the linear XY table and the workpiece is fixed on top of the rotary table. The orientation movement is driven by the workpiece;
- As a hybrid form of the above structures, Hybrid (HT) is designed as one rotary axis built on the spindle and the other on the XY table.

Step2: Configuring the Kinematic Chain

Then you should specify the Kinematic Chain based on the machine structure type selected on the step 1. The Kinematic chain relates 6 coordinate systems. The Machine Coordinate System contains 5 subsystems: Cartesian Drives, Work Piece, Primary, Secondary and Tool. Particularly, the Primary and Secondary systems should be set with a rotary axis from X, Y and Z.

After the rotary axes are specified, the offset and rotation of each subsystem can be set. The constant offset values for X, Y, Z should be set based on its reference system. Similarly, if there is a constant rotation between the current system and its reference system, then the Rotate Coordinate System check box should be chosen. The 1st and 2nd rotation axis and its angle value can then be configured separately.

Step3: Building the 5 Axis Machine

The configuration results can be displayed by clicking Build in and the machine with rotary axes will be presented.

The coordinate of each system can be turned on or off by clicking the Show Coordinate button and the Hide Coordinate button. The Rotate, Zoom and Pan buttons will help you view the virtual machine structure better.

Step4: Checking the Configuration Feasibility

It is necessary to check the configuration feasibility before proceeding by clicking the Configuration Feasibility Check button.

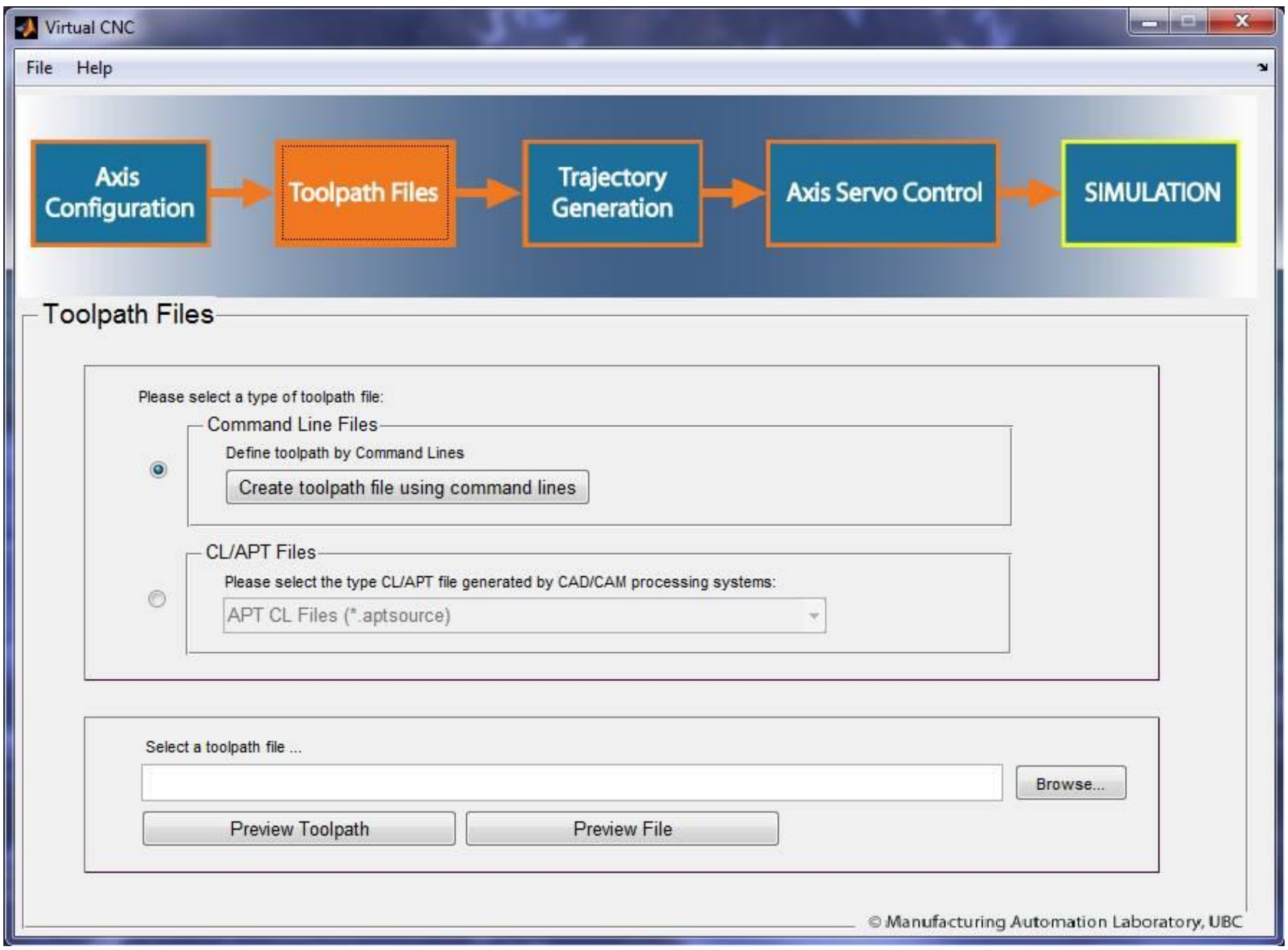
Step5: Save and quit

If the configuration is feasible after step 1-4, you should click the OK button to save the configuration and click the close button to quit.

1.3 Reference Toolpath File Configuration

Virtual CNC accepts reference toolpath generated on CAD/CAM system in the form of industry standard Cutter-Location(CL) format. Each block in the CL file contains NC block numbers, tool paths in the form of linear, circular and spline segments, the cutter dimensions, tool center coordinates and feed speed for machining a particular part on a CNC machine tool.

In the Toolpath Files module interface, options of reference toolpath type can be selected: Command Line File or CL/APT file.



If you select CL/APT file you should select a CL/APT file which has been generated from on CAD/CAM system.

If you select Command Line File, two options are given to define a toolpath:

- Click the button Create toolpath file using command lines to open the Command Line Window to define a toolpath.
- Click the button Browse to select a toolpath file. Some simple toolpath files are also provided in the Examples/CommandFileExample folder.

After selecting or defining a reference toolpath, click the button Preview Toolpath to check the toolpath and the button Preview File to check the file.

1.4 Trajectory Generation Configuration

In trajectory generation section, the tool path is interpolated into tiny segments according to different interpolation strategies. The data of each segment contain the position command for each axis, which decide the trajectory that cutter moves along. Different strategies can generate different feed profiles (tangential velocity profiles), as well as different command data for each axis, which may affect the dynamic performance and the work piece contour error.

In the trajectory generation module, you should configure four parts in the interface:

Kinematic Profile

Kinematic Profile section is designed for various feed profile options. The four feed profiles have different smooth orders. Trapezoidal

Velocity is the simplest with much more jerk, Cubic Acceleration will give smoothest feed profile, and Optimized Feedrate uses the optimized feed rate algorithm with a continuous jerk profile.

Input Shaping

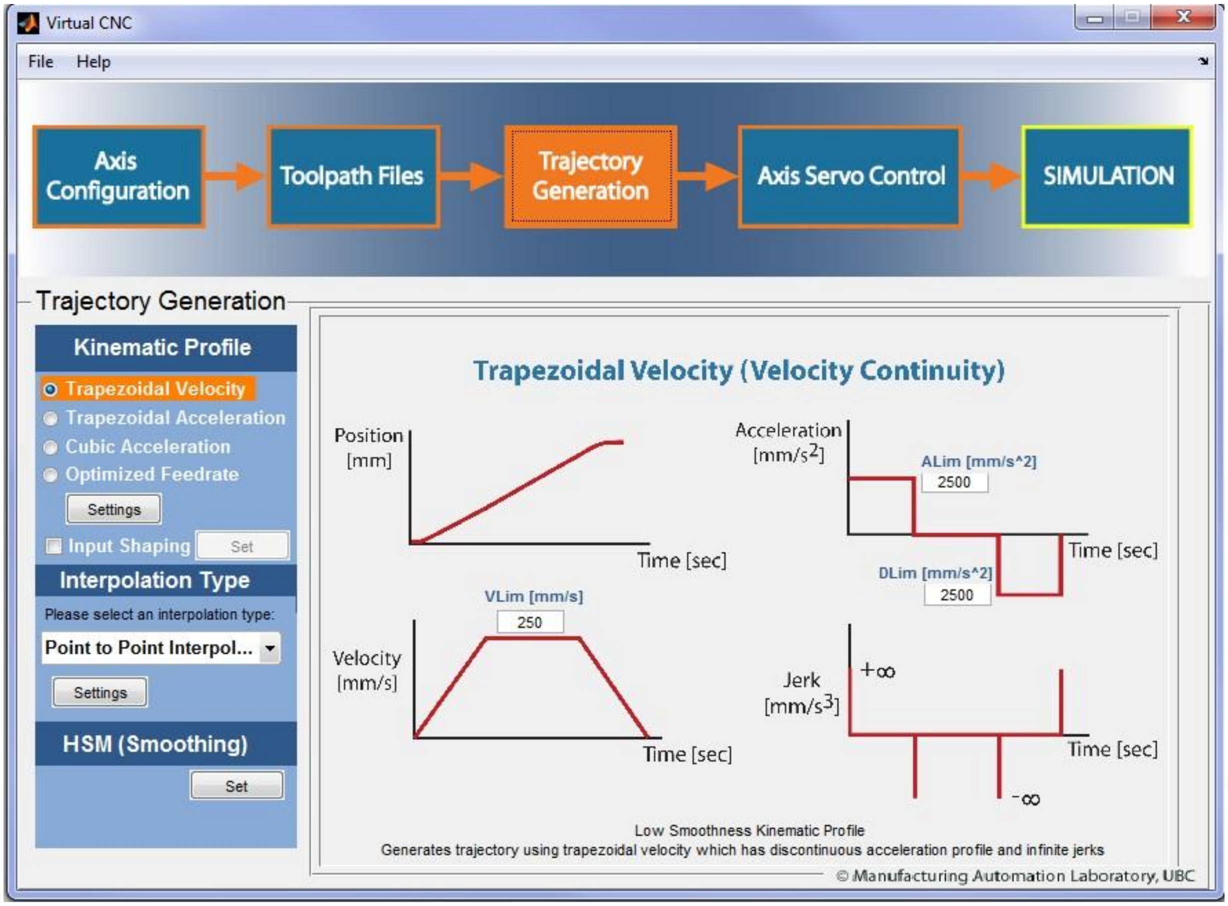
Input Shaping is a filtering technique to block those harmonics of the command which coincide with the structural modes of the axis drives. Frequency and damping of the structural mode is required in order to set a shaper which avoids excitation of that mode. There are currently three types of input shapers available in VCNC.

Interpolation Type

Interpolation Type affords options between Point to Point Interpolation and Continuous Interpolation. The tool path is treated as normal linear code (G01) in Point to Point Interpolation mode, and the feed will decrease to zero at the end of each line. In Continuous Interpolation mode, the linear tool paths will be connected with smooth corners if necessary, so the feed profile will be more efficient.

HSM (Smoothing)

In High Speed Machining, the joint limits are better to be concerned. When HSM is chosen, the constraints for each axis will be taken into consideration in trajectory generation.



1.4.1 Kinematic Profile Configuration

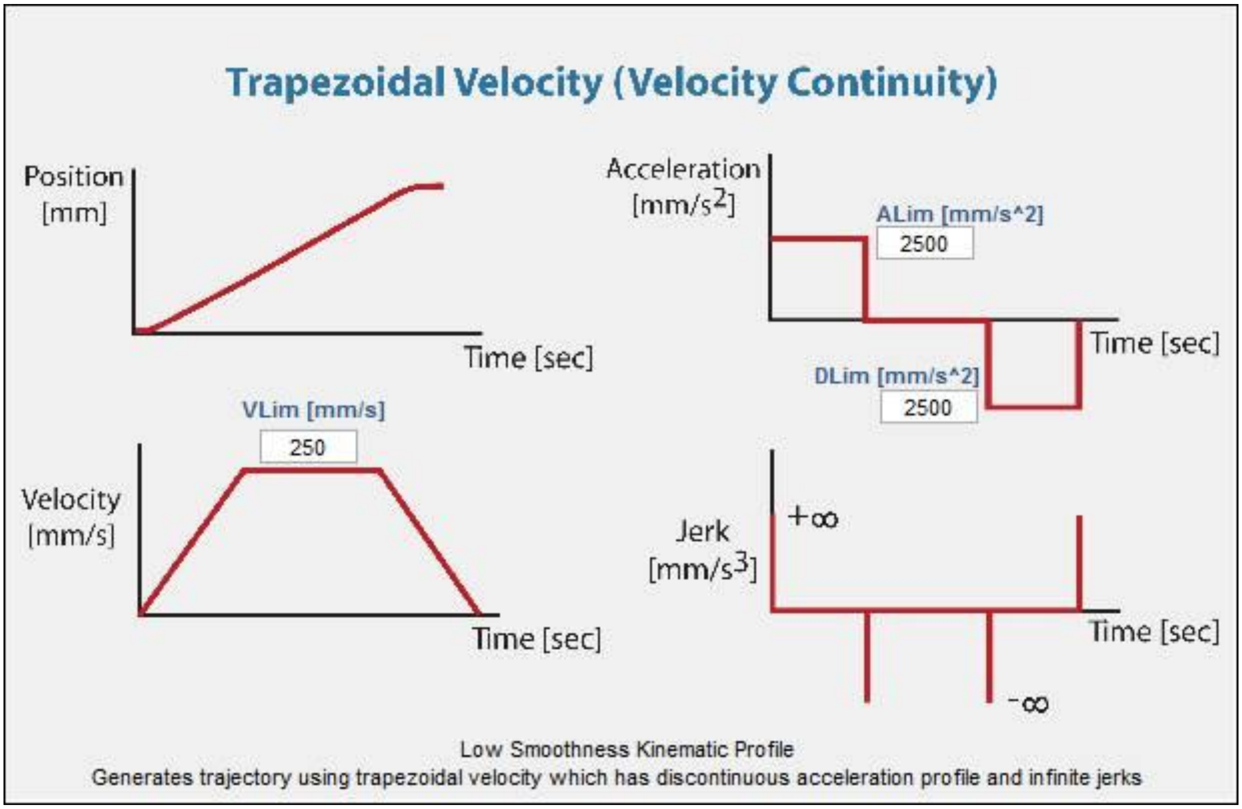
The configuration of "Kinematic Profile" includes four options: trapezoidal velocity, trapezoidal acceleration, cubic acceleration and optimized feedrate. The four feed profiles have different smooth orders. Trapezoidal Velocity is the simplest with much more jerk, while Cubic Acceleration will give smoothest feed profile.

You can choose one type by selecting the radial button and clicking the "Settings" button.

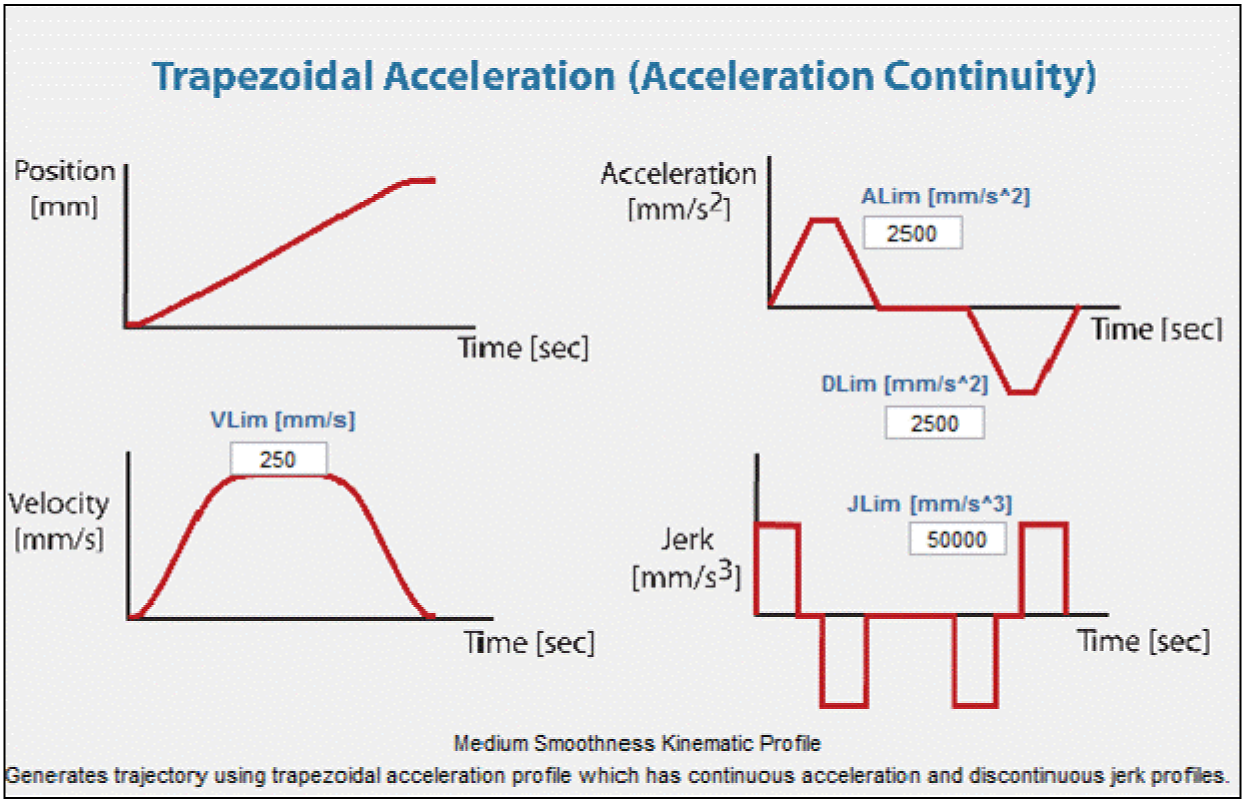
Then each interface of the three types will be open in the right part of the window.

The velocity limit, acceleration limit and jerk limit should be set properly.

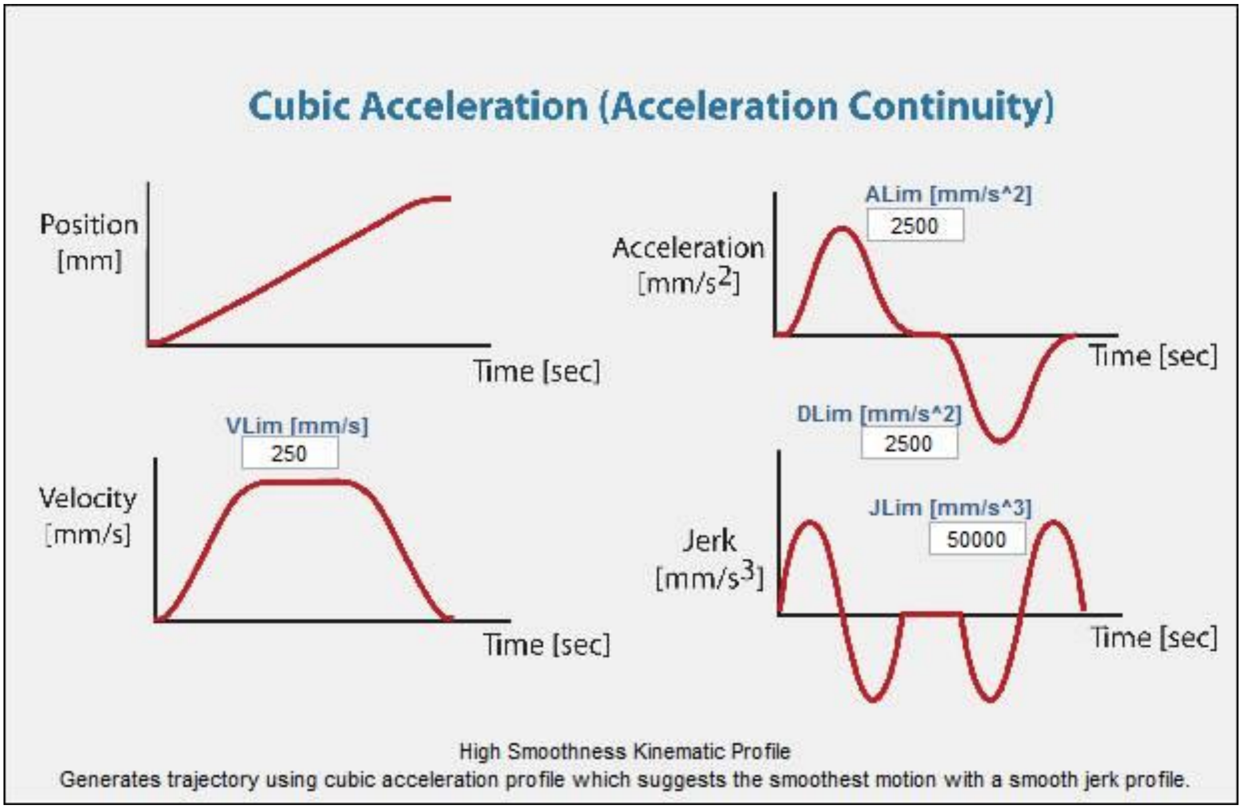
Trapezoidal Velocity



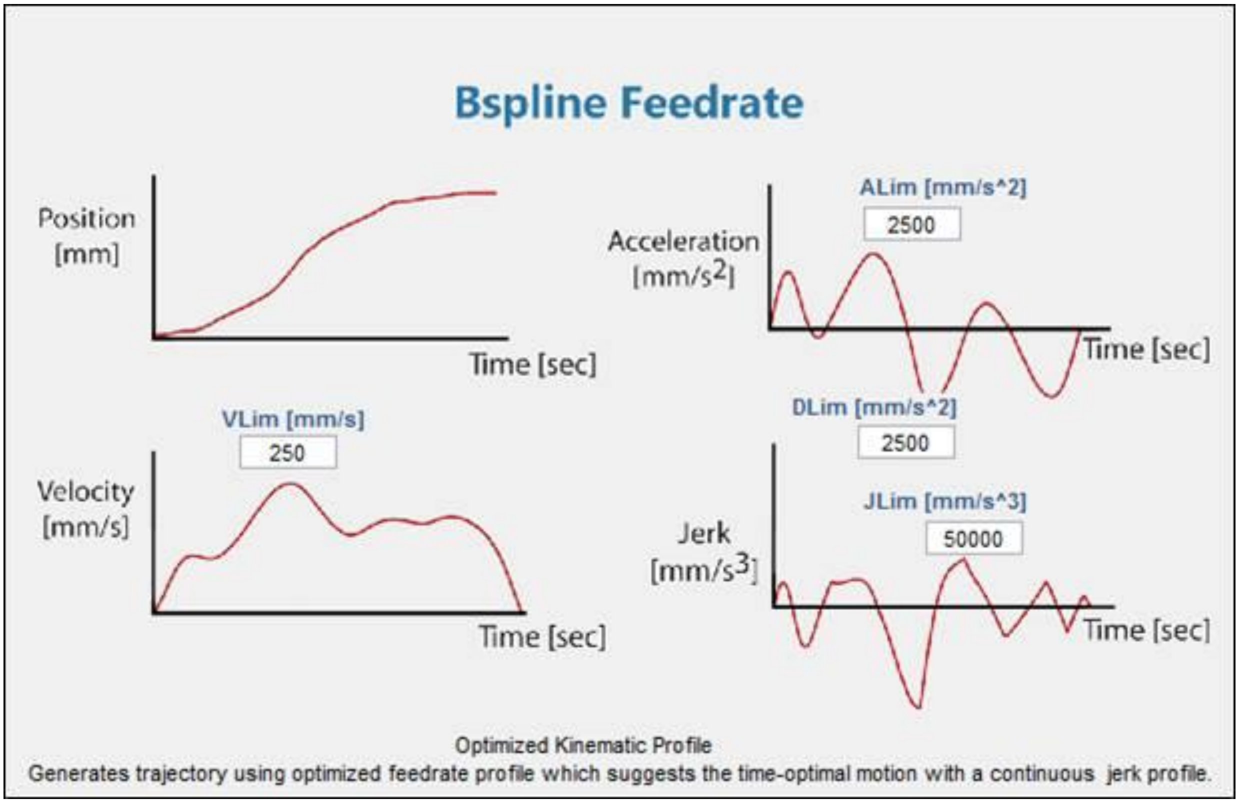
Trapezoidal Acceleration



Cubic Acceleration



Optimized Feedrate



1.4.2 Input Shaping

Input Shaping is a filtering technique to block those harmonics of the command which coincide with the structural modes of the axis drives. Frequency and damping of the structural mode is required in order to set a shaper which avoids excitation of that mode.

There are currently three types of input shapers available in Virtual CNC: ZV (Zero Vibration), ZVD (Zero Vibration and derivative), and EI (Extra-Insensitive).

The ZV shaper brings a half vibration period delay. The ZVD shaper causes a delay equal to a full vibration period, and consequently, larger trajectory distortion effect.

However, ZVD shaper is significantly more robust than ZV shaper, which makes it preferable for the cases where the actual frequency may deviate from the modeled one by more than 5%.

EI shaper also causes one full vibration period and is slightly more robust than ZVD.

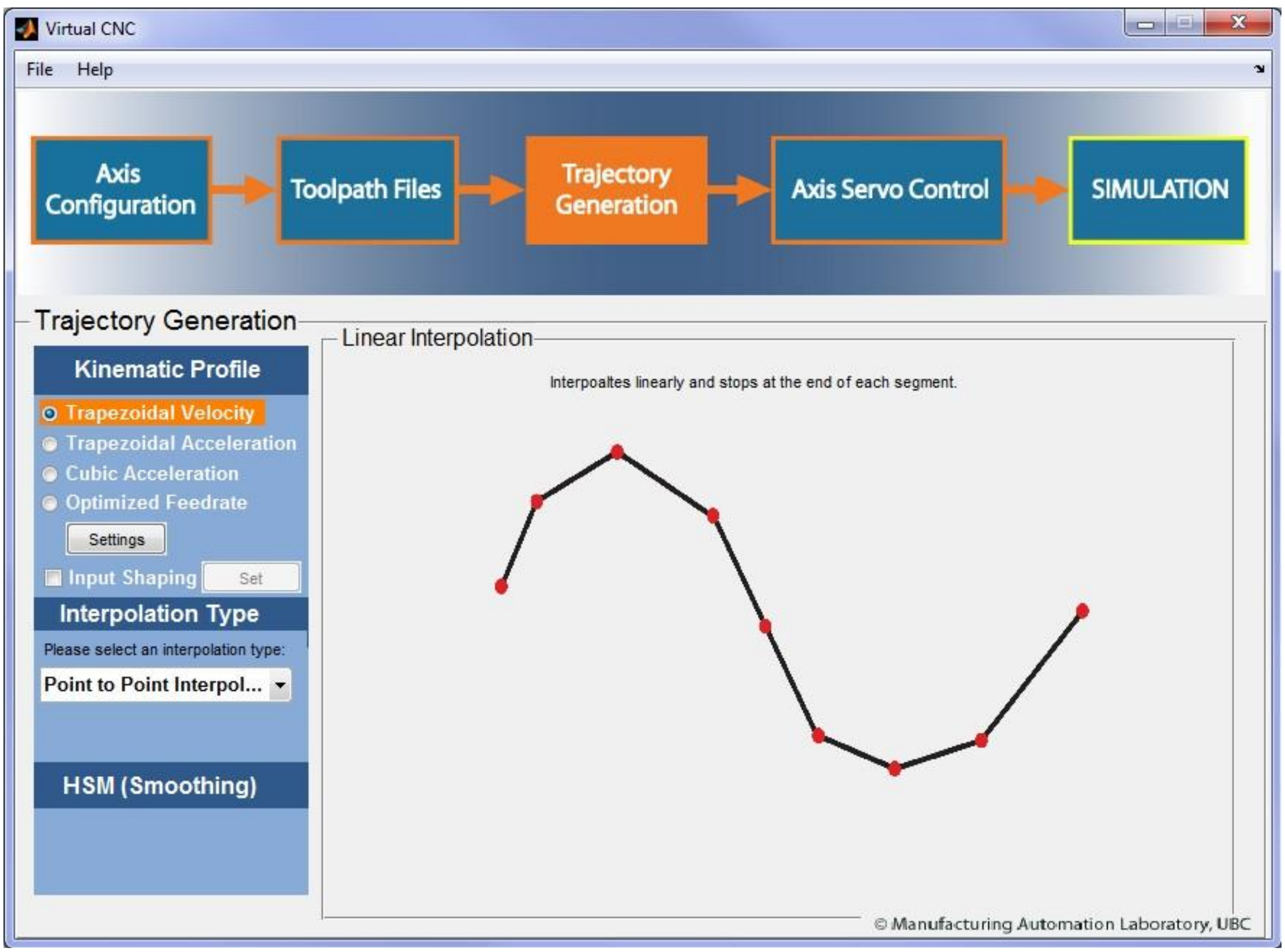
1.4.3 Interpolation Configuration

Interpolation Type affords options between "Point to Point Interpolation" and "Continuous Interpolation".

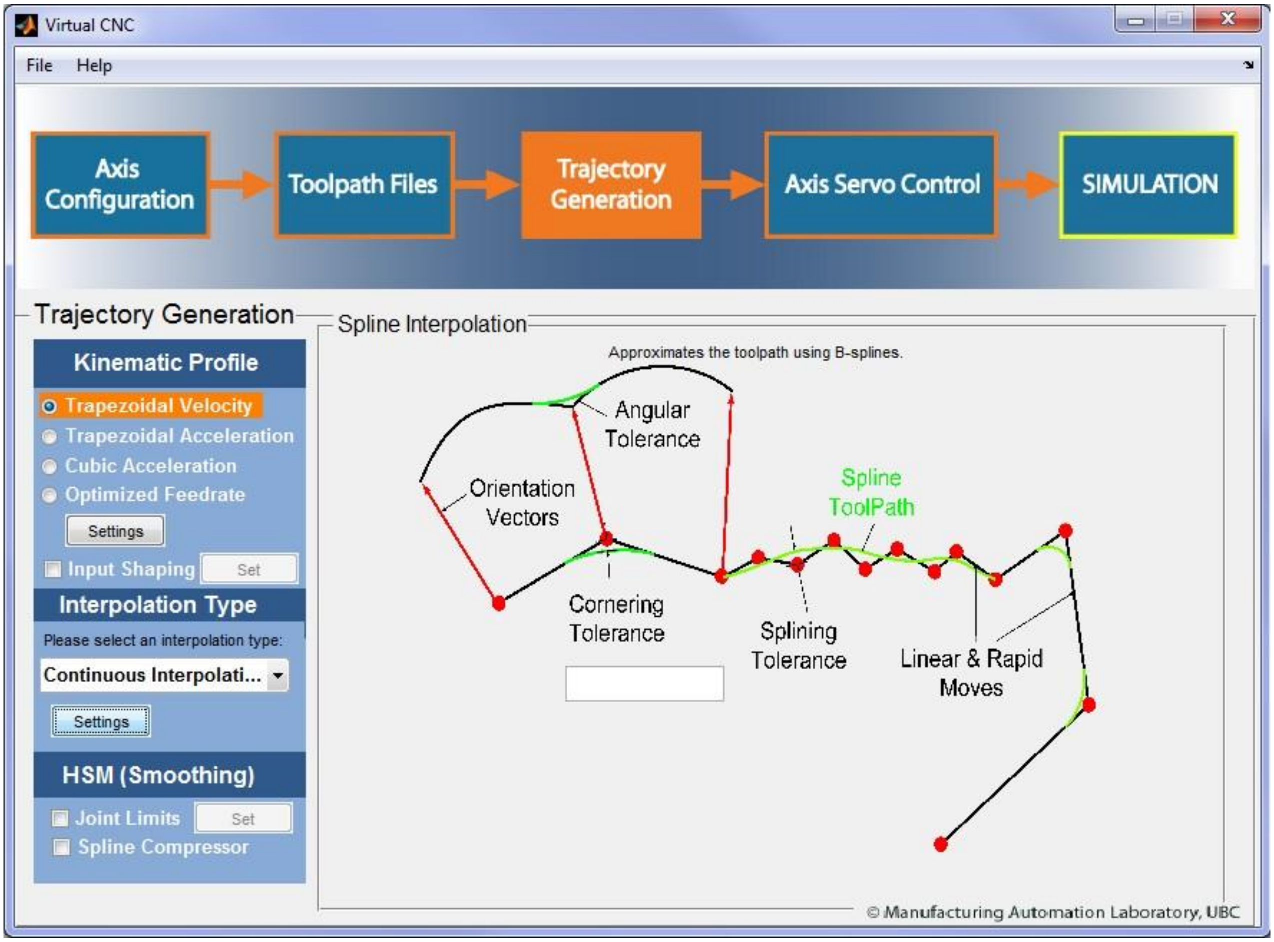
The tool path is treated as normal linear code (G01) in "Point to Point Interpolation" mode, and the feed will decrease to zero at the end of each line.

In "Continuous Interpolation" mode, the linear tool paths will be connected with smooth corners if necessary, so the feed profile will be more efficient.

Point to Point Interpolation



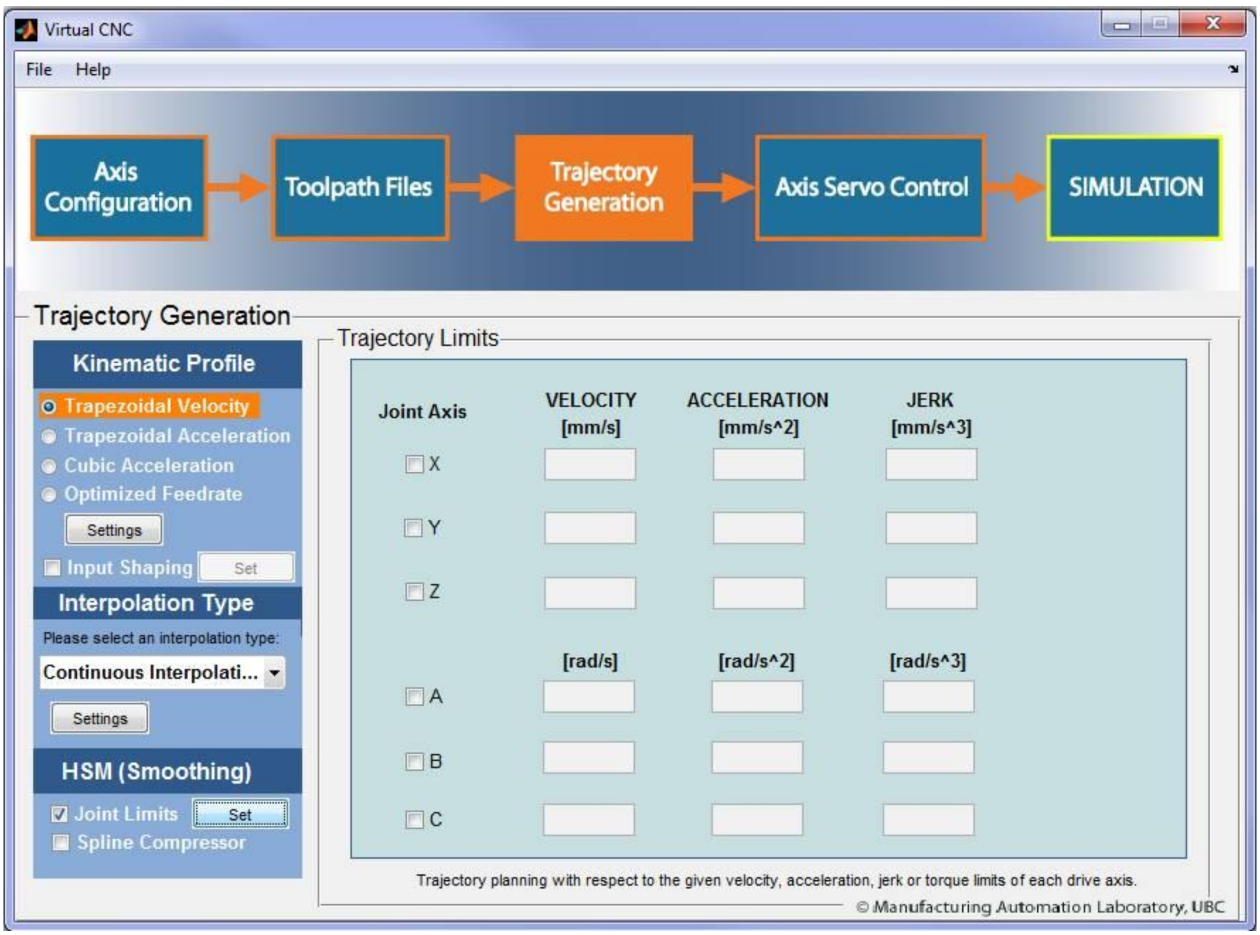
Continuous Interpolation



1.4.4 HSM (Smoothing) Configuration

The HSM (Smoothing) has two options: **Joint Limits** and **Spline Compressor**.

If you check the Joint Limits, you should click set icon to configure the parameters in the Trajectory Limits interface.



If you check the Spline Compressor, the spline compressor will be applied for your project as a smoothing type.

1.5 Axis Servo Control Configuration

In Virtual CNC, you can select control law, lead screw, ball screw or linear drive parameters, as well as amplifier, motor, friction field and sensor so that most machine tools can be reconfigured automatically.

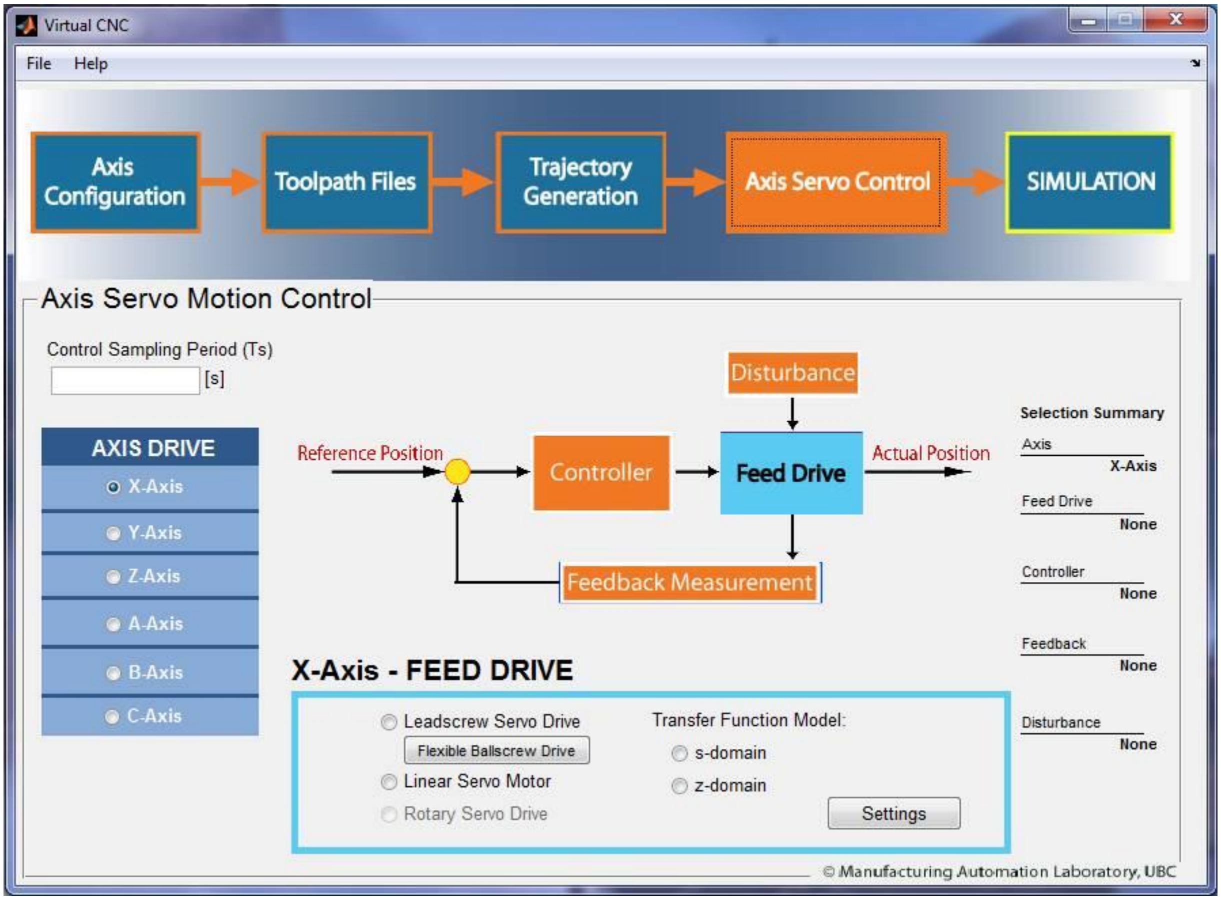
The axis commands are passed on to the control law, which shapes the overall response of the feed drive transfer function, consisting of Digital to Analog(D/A) converter, amplifier, servo motor, inertia, viscous damping, guideway friction and lead screw backlash.

The axis can be configured to have acceleration, velocity and position sensors with defined accuracy and noise parameters. The position error of each axis is evaluated in the feedback loop and combined to predict the contouring error at each control interval.

Configuring the Axis Servo Control Module includes configuring the **FeedDrive**, **Controller**, **Disturbance** and **Feedback Measurement** for each axis.

The axis drive and the control sampling period should be selected first and then the servo control will be configured based on the specified axis.

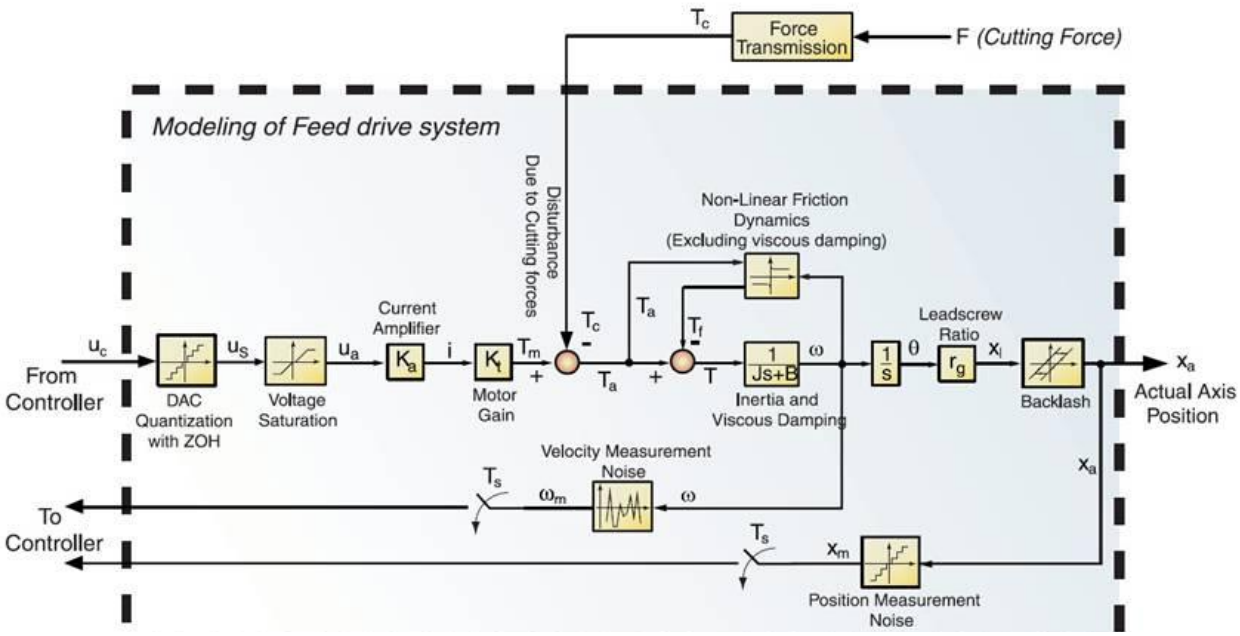
The A-Axis, B-Axis and C-Axis are available only in the 5-axis machining.



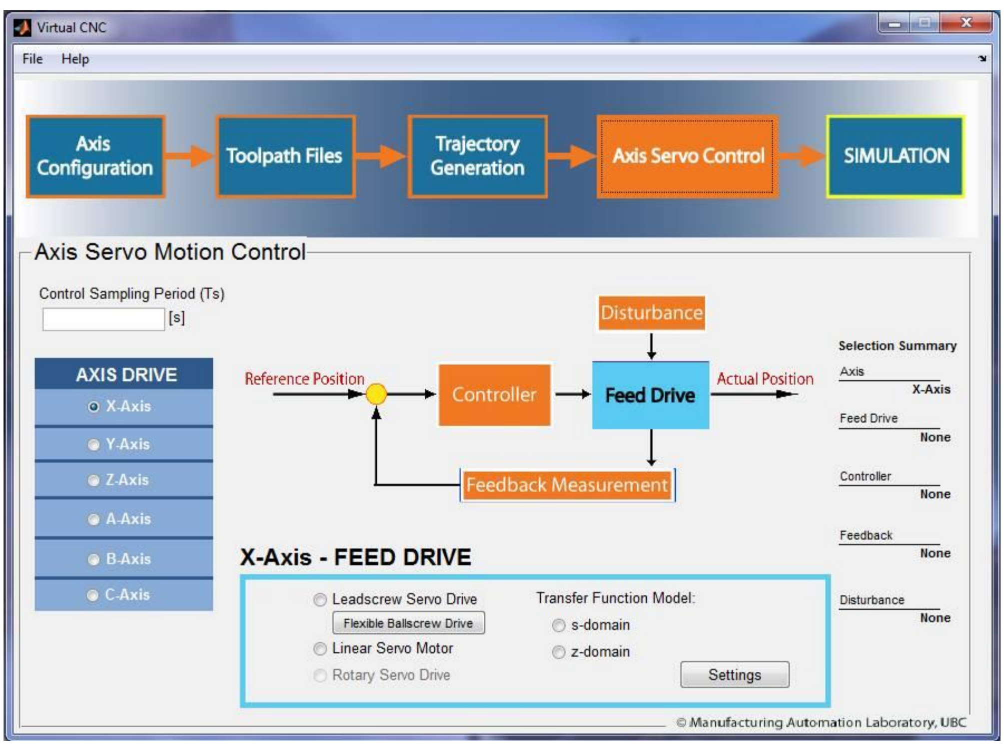
1.5.1 Feed Drive Configuration

The parametric model of the overall feed drive is shown below. Virtual CNC includes four types of models to select for the axis feed drive:

Leadscrew Servo Drive, **Linear Servo Motor**, **Rotary servo Drive**, and **Transfer Function model** include two types: **s-domain** and **z-domain**.



When the **Feed Drive** icon is highlight in the interface of Axis Servo Control module, you can see the configuration interface.

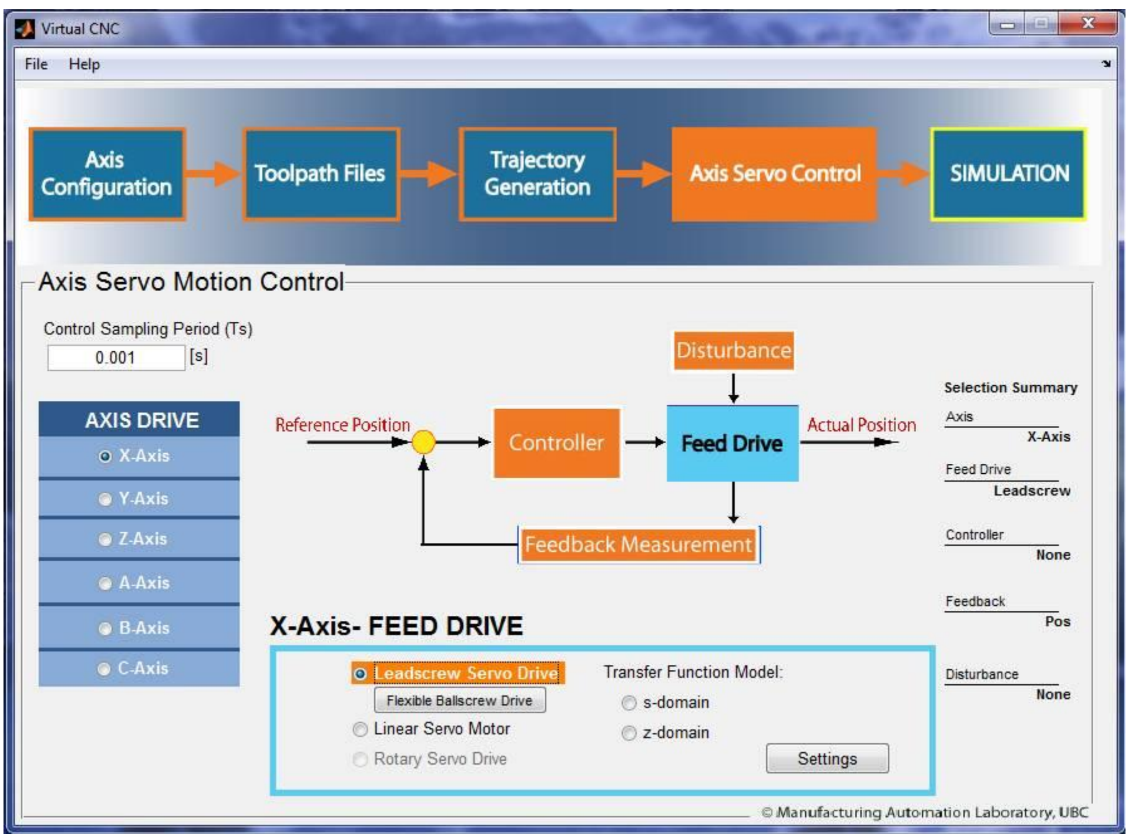


1.5.1.1 Leadscrew Servo Drive Configuration

The leadscrew servo drive includes two types: **Rigid-Body Dynamics Drive** and **Flexible Ballscrew Drive**.

If you select the **Rigid-Body Dynamics Drive**, you can configure it by clicking the radial button before the **Leadscrew Servo Drive** first and then clicking the **Settings** button to open the configuration interface of the rigid-body dynamics drive.

If you select the **Flexible Ballscrew Drive**, you can configure it by clicking the radial button before the**Leadscrew Servo Drive** first and then clicking the **Flexible Ballscrew Drive** button to open the configuration interface of the flexible ballscrew drive.

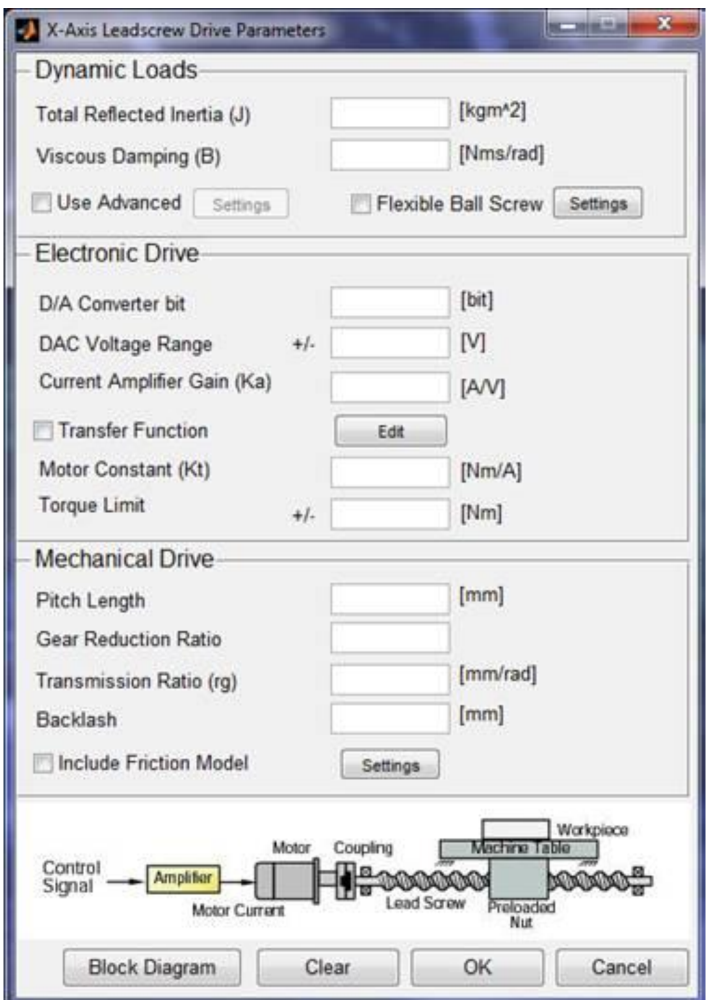


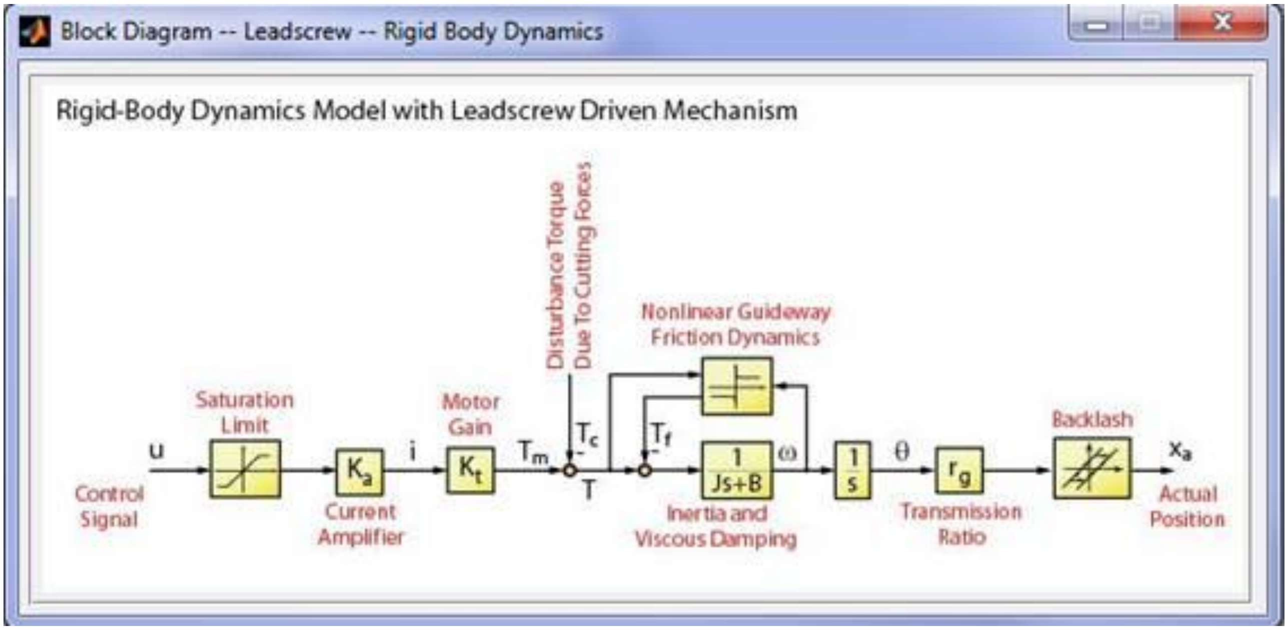
1.5.1.2 Leadscrew Servo Drive (Rigid-Body Dynamics)

When selecting the **Leadscrew Servo Drive** and clicking the**settings** icon, you can open the interface of drive parameters and input physical parameters of the drive.

Three sections of the parameters for the rigid body dynamics drive should be set up properly: **Dynamic Loads**, **Electronic Drives** and **Mechanical Drive**.

By clicking the **Block Diagram** button on the bottom of the interface, you can see the block diagram structure of **Rigid-Body Dynamics Model** with **Leadscrew drive** mechanism.





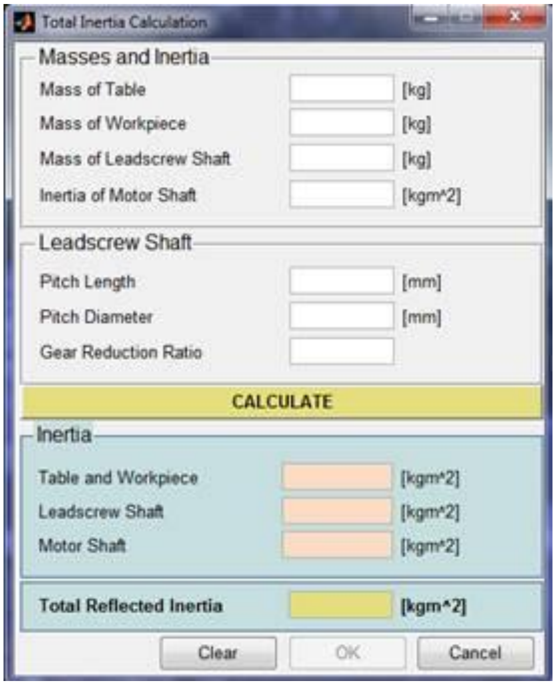
Dynamic Loads:

In this section the values of total reflected inertia and viscous damping are set up.

Alternately, you can check and select **Use Advanced**. After click the **Settings** button, you can open the interface of **Total Inertia Calculation** and then need input the mass and inertia of each component of the lead drive.

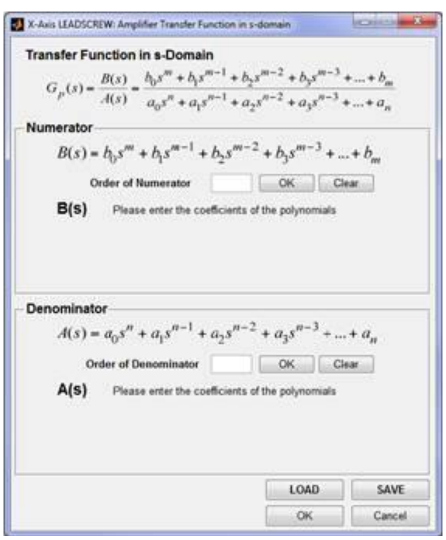
After clicking the **CALCULATE** icon, the total reflected inertia will be calculated and shown in the dialog box.

Electronic Drive:



The current amplifier can be defined either by a constant gain (Ka) or by a transfer function.

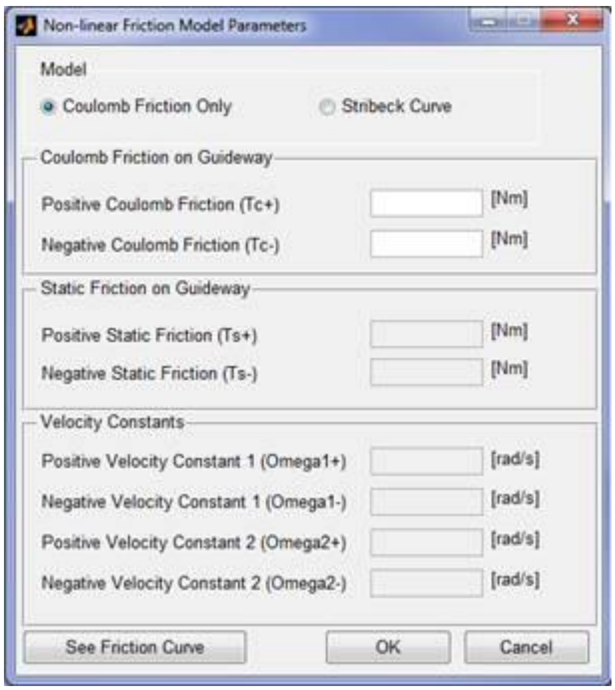
When you check the **Transfer Function**, and click the **Edit** icon, you can define the polynomial order and coefficients of the numerator and denominator of the amplifier transfer function.



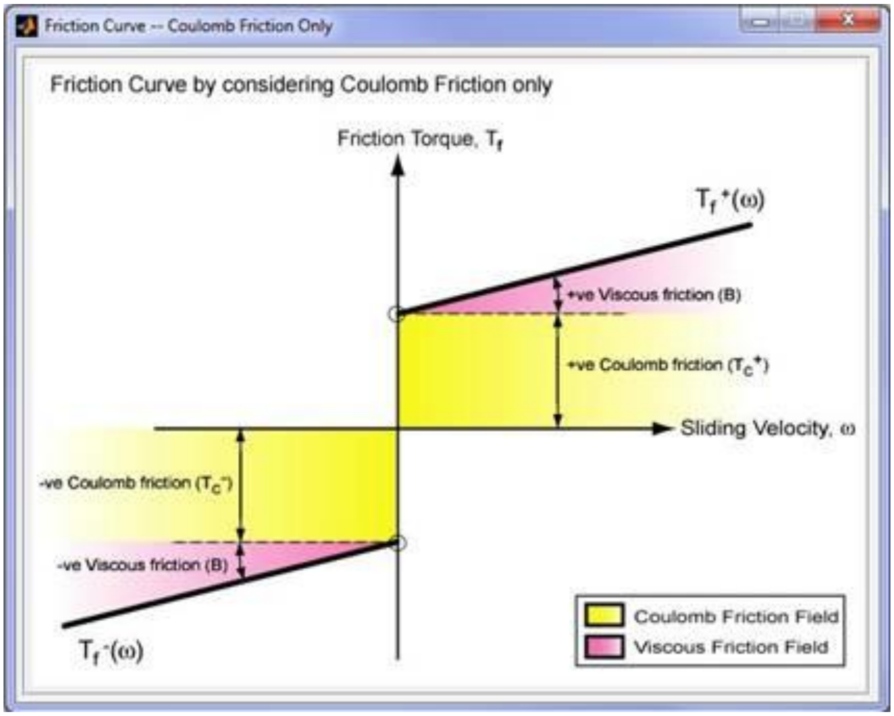
Mechanical Drive:

In this section, you can include the friction in the feed drive model.

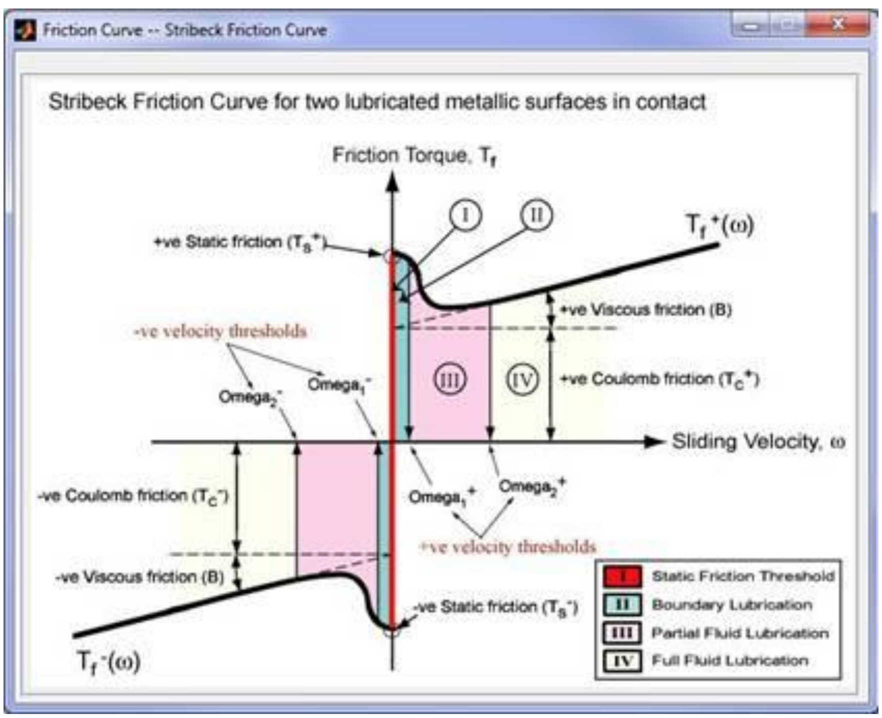
By checking the **Include Friction Model** and clicking **Settings** button, the interface of **Non-linear Friction Model Parameters** will open.



Then you can select between two types of models: **Coulomb Friction** and **Stribeck Friction**, and specify the friction parameters. The friction curve will be shown after you click the **See Friction Curve** icon.



Friction Curve -- Coulomb Friction Only
Friction Curve by considering Coulomb Friction only
Friction Torque, T_f
$T_f^+(\omega)$
+ve Viscous friction (B)
+ve Coulomb friction (T_C^+)
Sliding Velocity, ω
-ve Coulomb friction (T_C^-)
-ve Viscous friction (B)
$T_f^-(\omega)$
Coulomb Friction Field
Viscous Friction Field

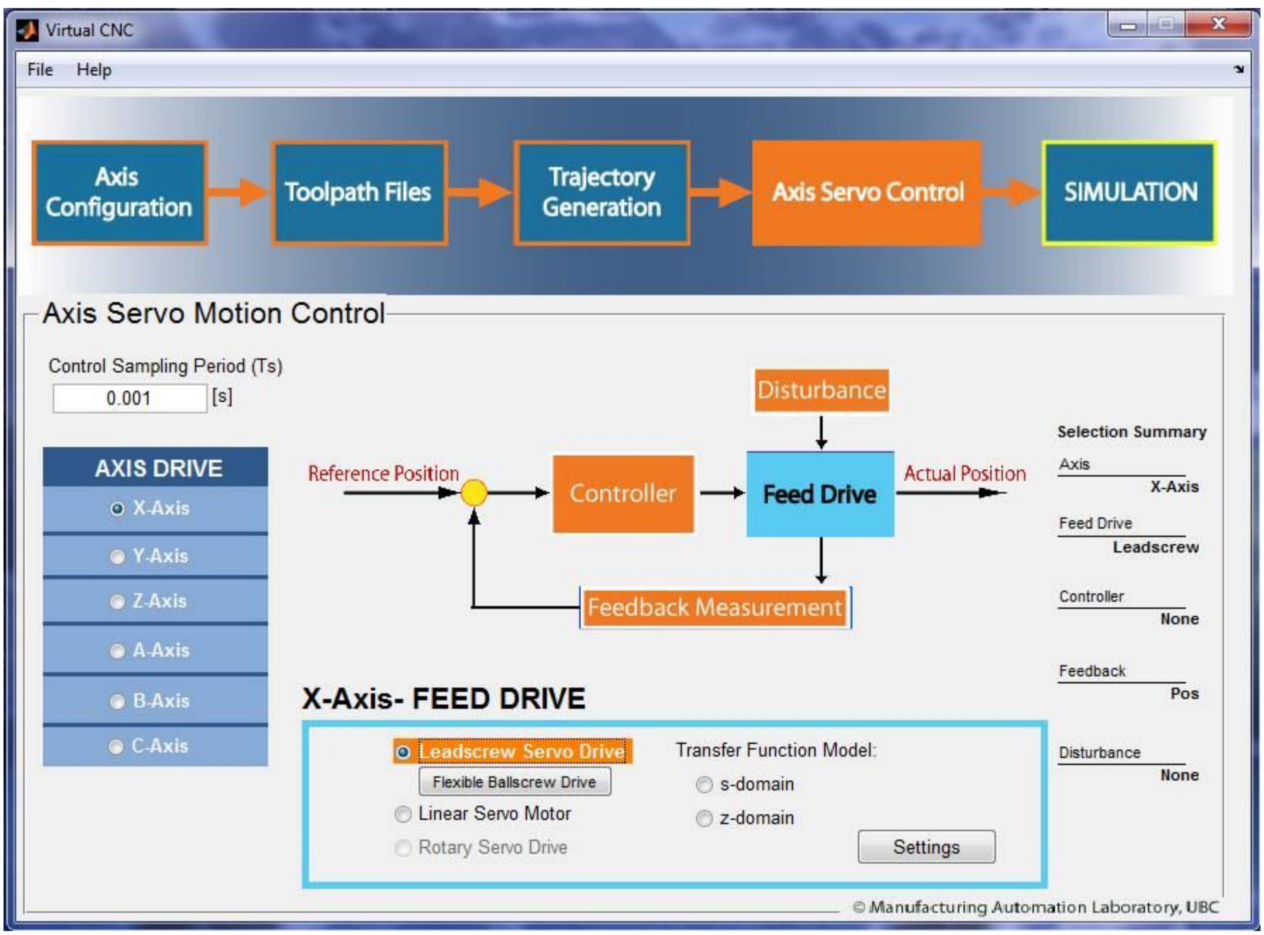


Friction Curve -- Stribeck Friction Curve
Stribeck Friction Curve for two lubricated metallic surfaces in contact
Friction Torque, T_f
I
II
$T_f^+(\omega)$
+ve Static friction (T_S^+)
+ve Viscous friction (B)
-ve velocity thresholds
Omega$_2^-$
Omega$_1^-$
III
IV
+ve Coulomb friction (T_C^+)
Sliding Velocity, ω
-ve Coulomb friction (T_C^-)
Omega$_1^+$
Omega$_2^+$
+ve velocity thresholds
-ve Viscous friction (B)
-ve Static friction (T_S^-)
$T_f^-(\omega)$
I Static Friction Threshold
II Boundary Lubrication
III Partial Fluid Lubrication
IV Full Fluid Lubrication

1.5.2 Flexible ball screw Configuration

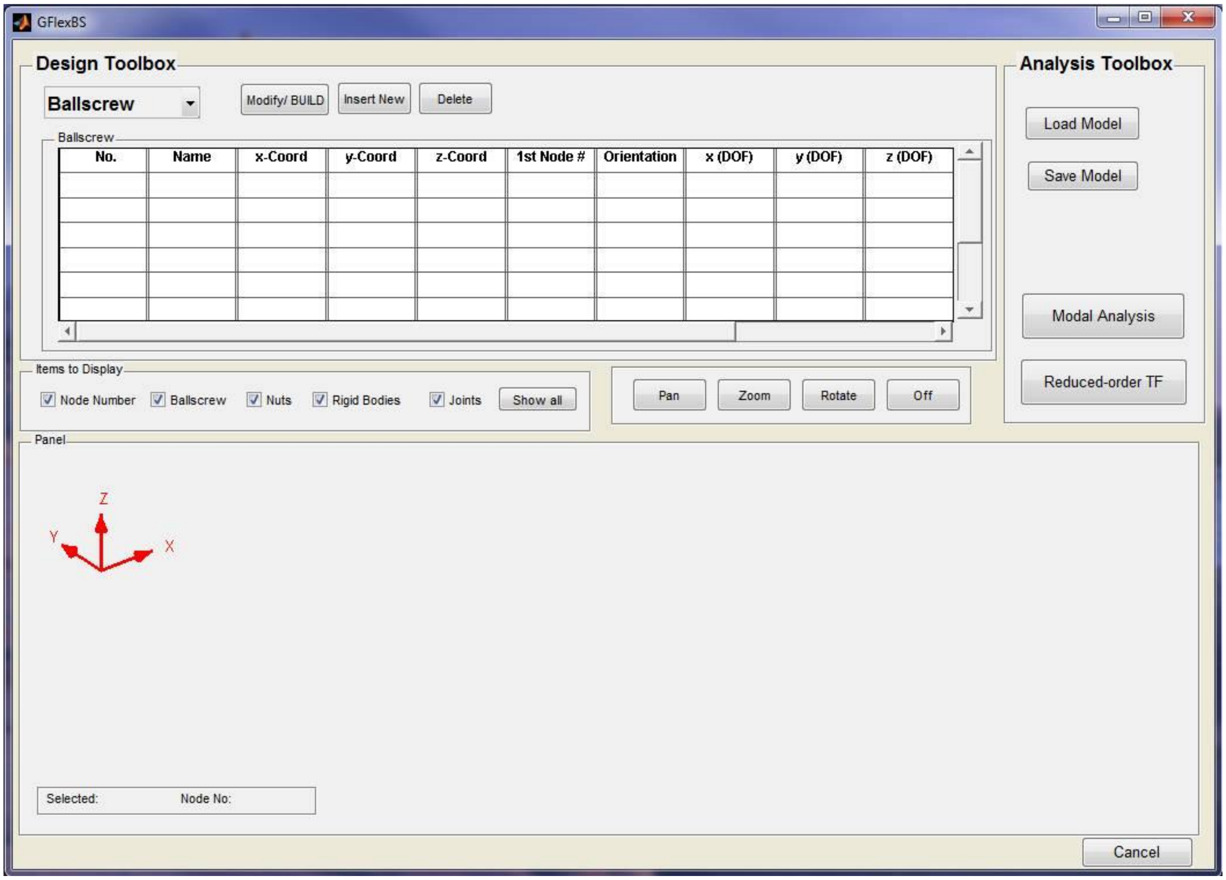
Ball screw drives provide thrust and linear motion at the machine tool table by transmitting power from a rotary motor through a ball screw mechanism. They are commonly used in machine tools because of their relatively high stiffness to cutting force disturbances and low sensitivity to variations in workpiece inertia as a result of their inherent gear reduction ratio.

If you select a ball screw drive for one axis, you should configure the axis drive in this section. Click the **Feed Drive** icon in the Axis Servo Drive module, and when the **Feed Drive** icon is highlighting, select the **Leadscrew Servo Drive** radial button and click the **Flexible ballscrew Drive** icon below.



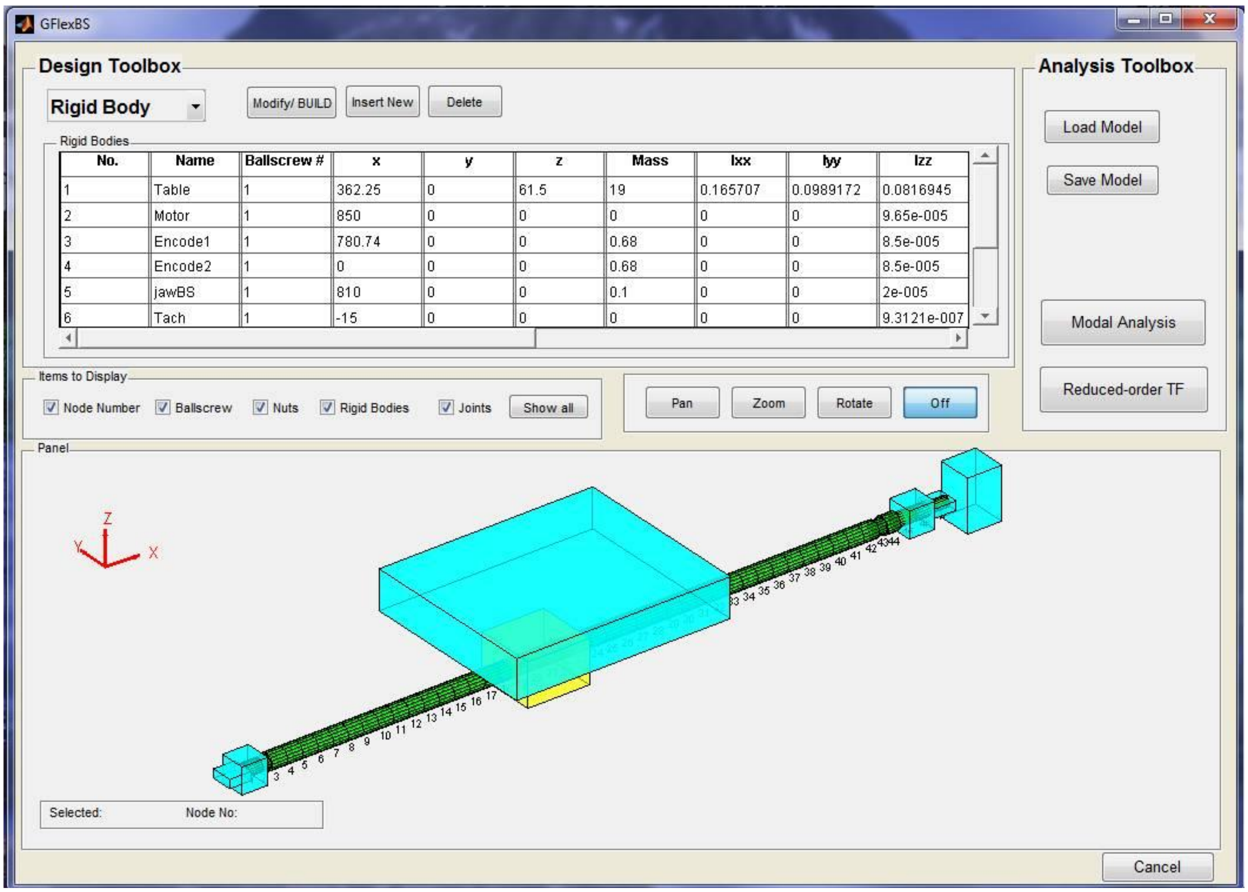
This opens the structure design interface of the flexible ballscrew drive.

Configuration of a ball screw drive includes three steps:
Modeling, Analysis, and **Loading the result.**



1.5.2.1 Modeling a Ballscrew Drive

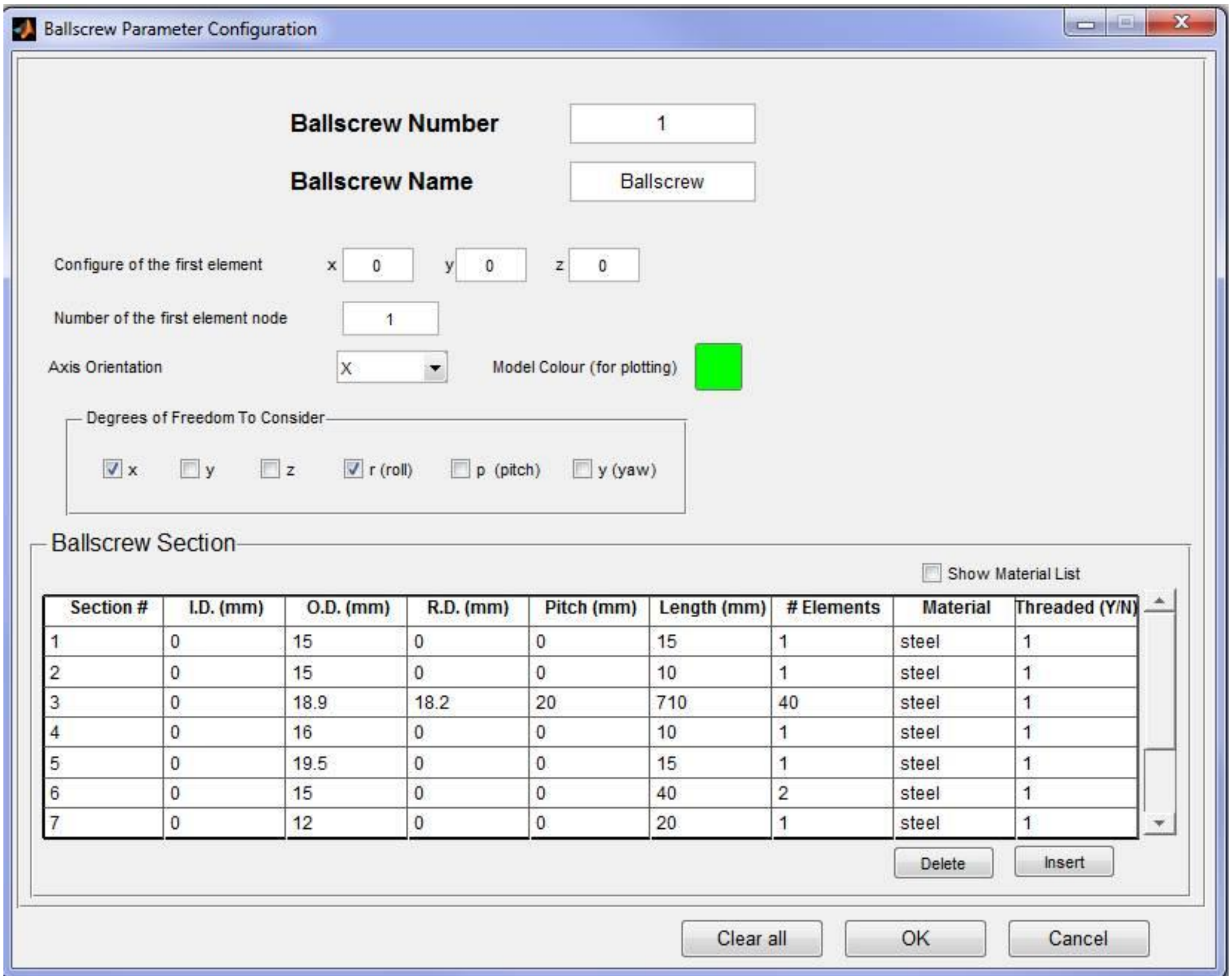
Click the **Feed Drive** icon in the Axis Servo Drive module, and when the **Feed Drive** icon is highlighting, select the **Leadscrew Servo Drive** radial button and click the **Flexible ballscrew Drive** icon below. This opens the structure design interface of the flexible ballscrew drive.



By clicking the **Load Model** button in the **Analysis Toolbox,** you can select an existing flexible ballscrew drive model under the file path Virtual CNC /Ballscrew / ubcBS.mat. After loading the structure of the example ballscrew can be shown in the interface.

In the **Design Toolbox**, you can select one of the four types of the structure: **Ballscrew, Nut, Rigid Body** and **Joint**. Then by clicking one item of the table and the **Modify, Insert New** or **Delete** button, you can design the structure.

For example: after selecting **Ballscrew**, clicking the No.1 item in the ballscrew table, and clicking the **Modify/BUILD**button, the interface of **Ballscrew Parameter Configuration** will be open. Then you can configure the parameters of the ballscrew.



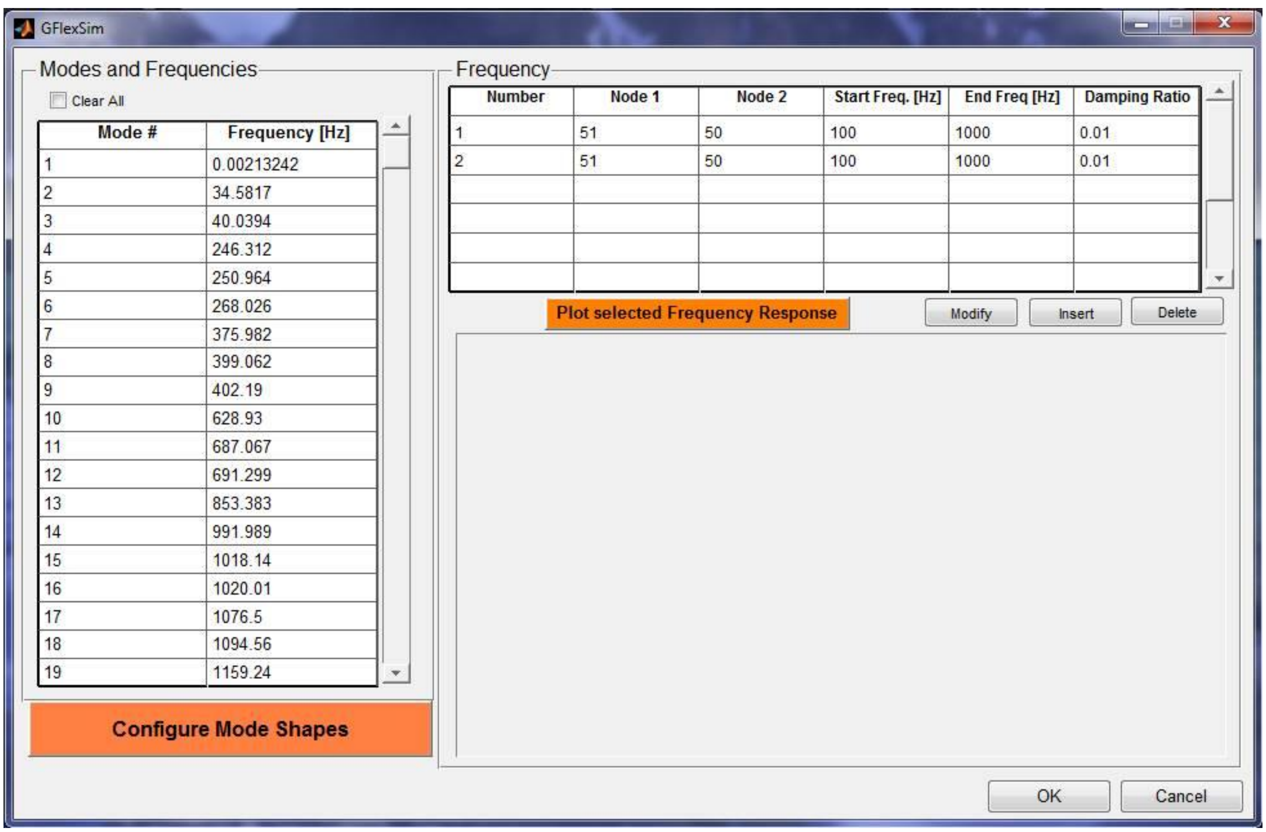
After modeling a new ballscrew structure, you should save your new model by clicking the **Save Model** button in the **Analysis Toolbox**.

1.5.2.2 Analysis of a Ballscrew Drive

You can analyze the FRF of a ballscrew drive by clicking the **Modal Analysis** button and export the transfer function result of the ballscrew drive by clicking the **Reduced-order TF** button in the **Analysis Toolbox**.

- **Modal Analysis:**

After clicking **Modal Analysis** button, this interface will open. Selecting a row in the **Frequency** table and clicking the **Plot selected Frequency Response** button, you can see the plot of the frequency response function for the designated nodes number and the frequency range.

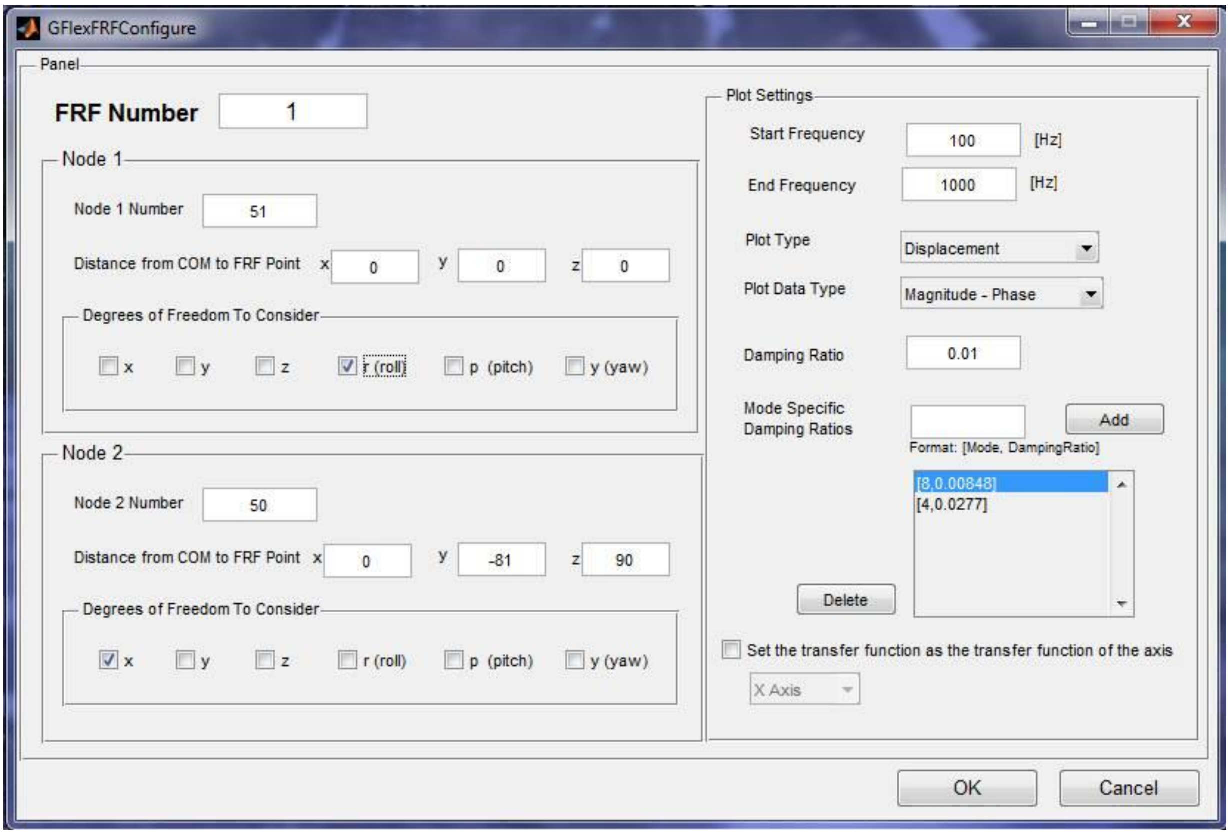


Before the plot, maybe you need **Modify, Insert** or **Delete** the configuration of the row you want.

Taken **Modify** as an example, you can select the row Number you want in the **Frequency** table and click the **Modify** button to open the FRF configuration interface.

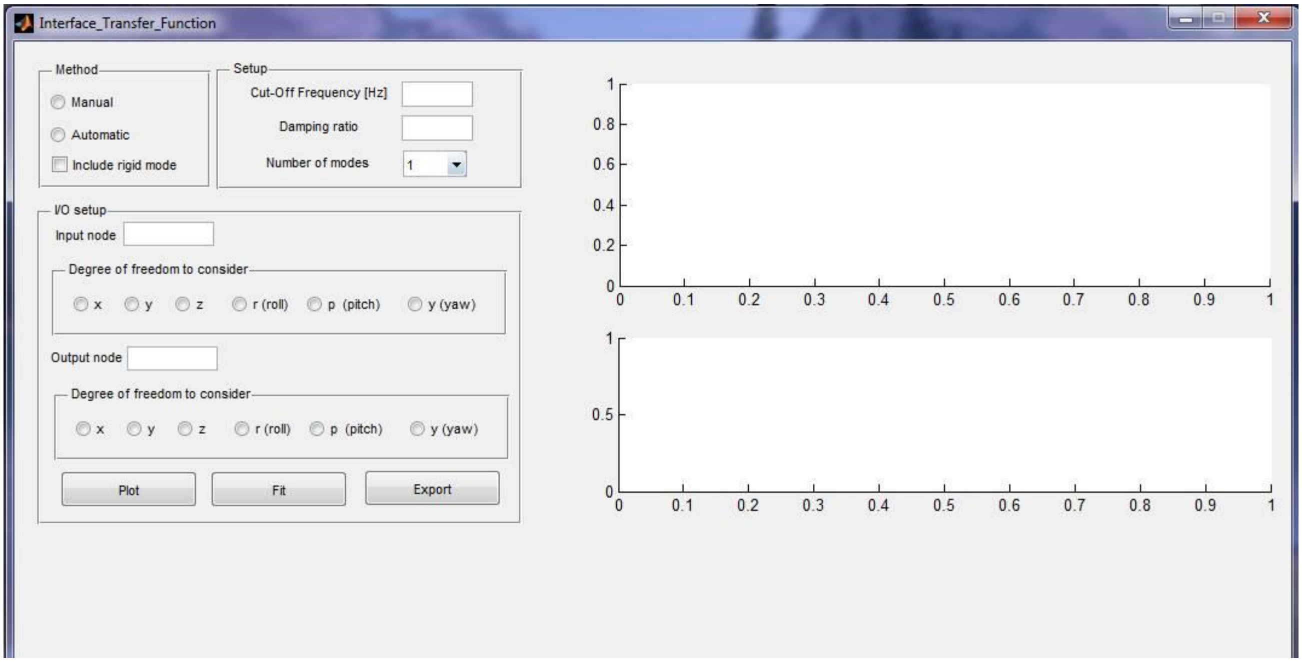
The Nodes parameters and the plot settings should be configured based on your model properly. After configuration, click the **OK** button to save.

Plot the frequency response function again after the FRF configuration, and see a new FRF result.



- **Reduced-order TF**

In the structure design interface of the flexible ballscrew drive, clicking the **Reduced-order TF** button in the **Analysis Toolbox**, you can plot, fit and export the transfer-function.



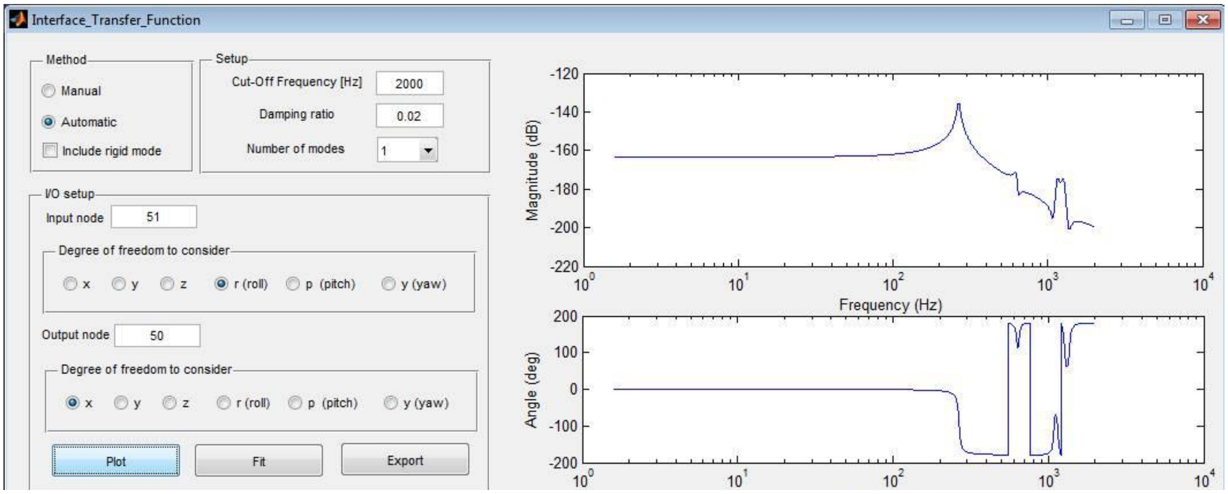
You should define all the parameters in the **Method**, **Setup** and **I/O setup** sections first.

It includes defining **Manual** or **Automatic**, if you want to **include rigid mode**, **Cut-Off Frequency**, **Damping ratio** and **the number of modes**, **input node** and **output node**.

After finishing the definition of all the parameters, click the **Plot** button, the magnitude and phase angle of the frequency response function will be shown.

Click the **Fit** button and the frequency response function curves from the finite element model are fitted and plotted.

Click the **Export** button to export and save the transfer function file of the flexible ballscrew drive model, which is saved as a tf file. The coefficients of the ballscrew drive transfer function can be extracted from the .tf file and input in the transfer function model in s-domain.

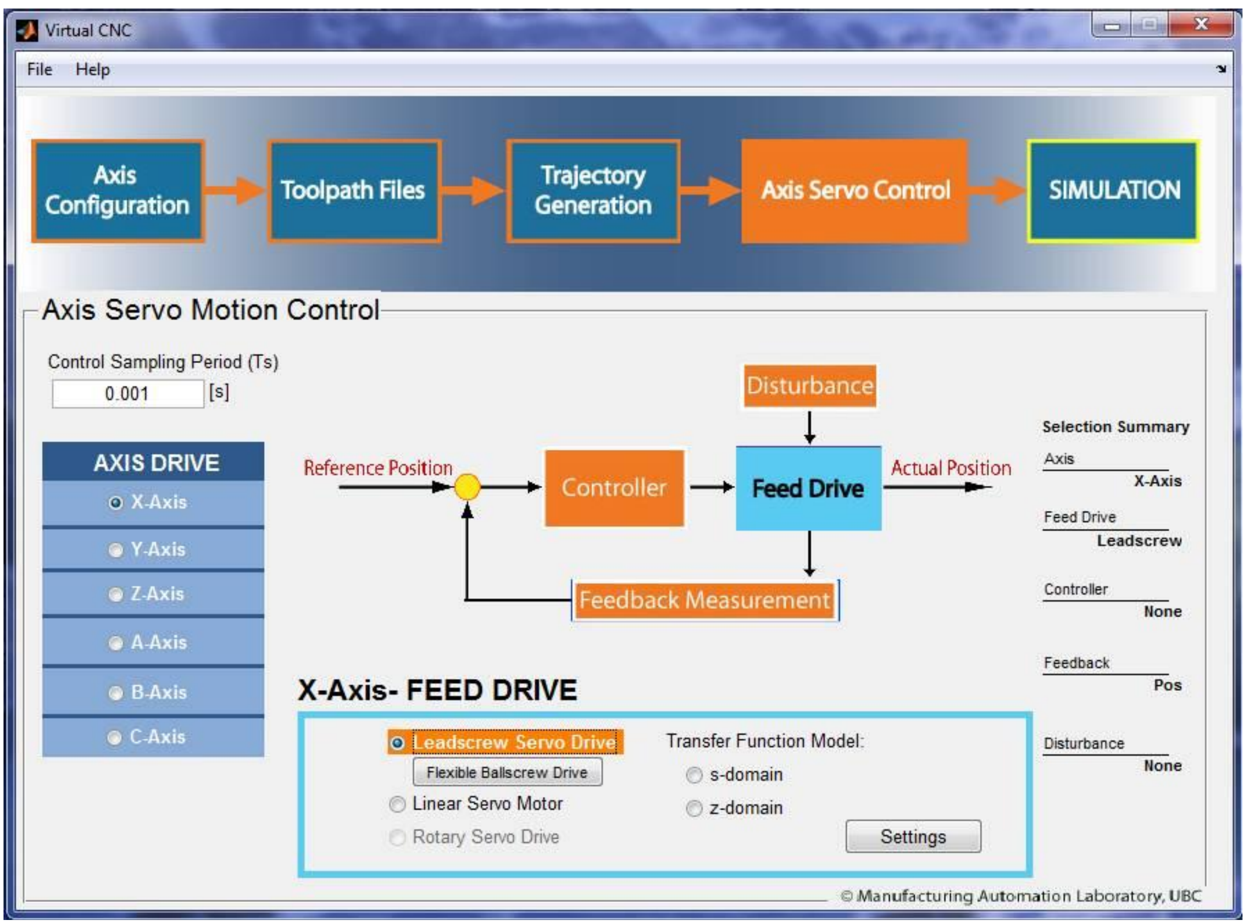


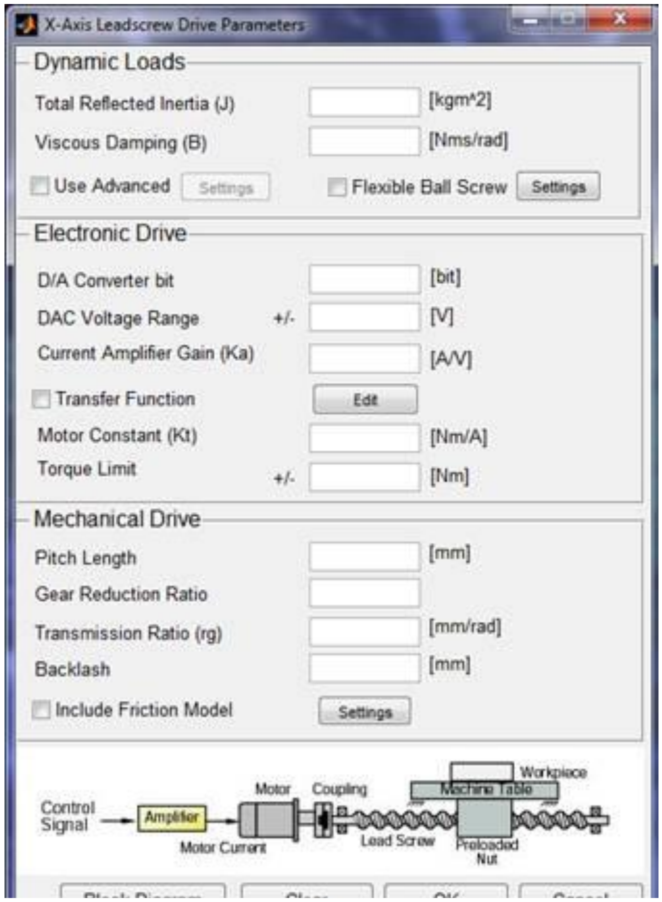
Close the configuration interfaces of the flexible ballscrew.

1.5.2.3 Loading the Transfer Function of a Ballscrew Drive

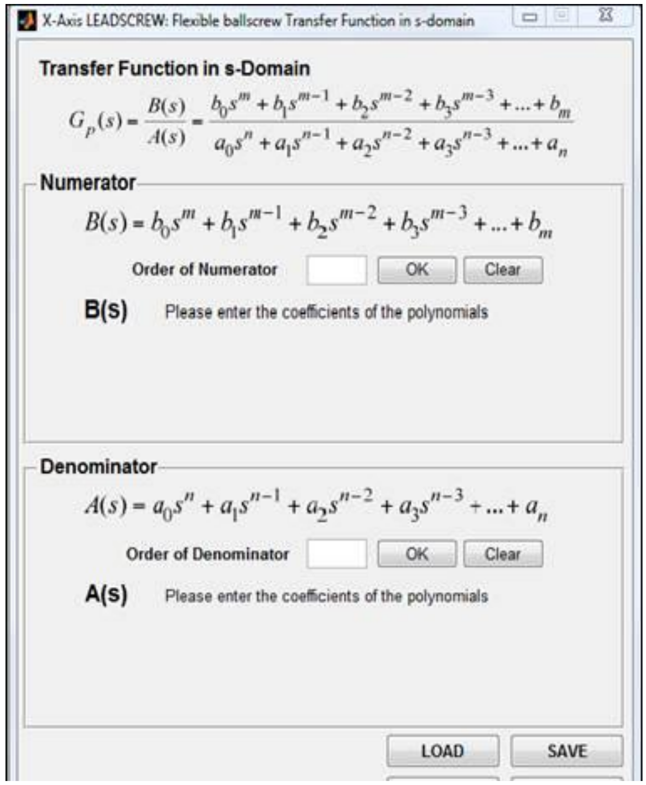
If you want to import the transfer function, which was exported from the flexible ball screw module to replace the parameters of J and B in rigid body model, you should open the interface of the **Leadscrew Drive Parameters** first.

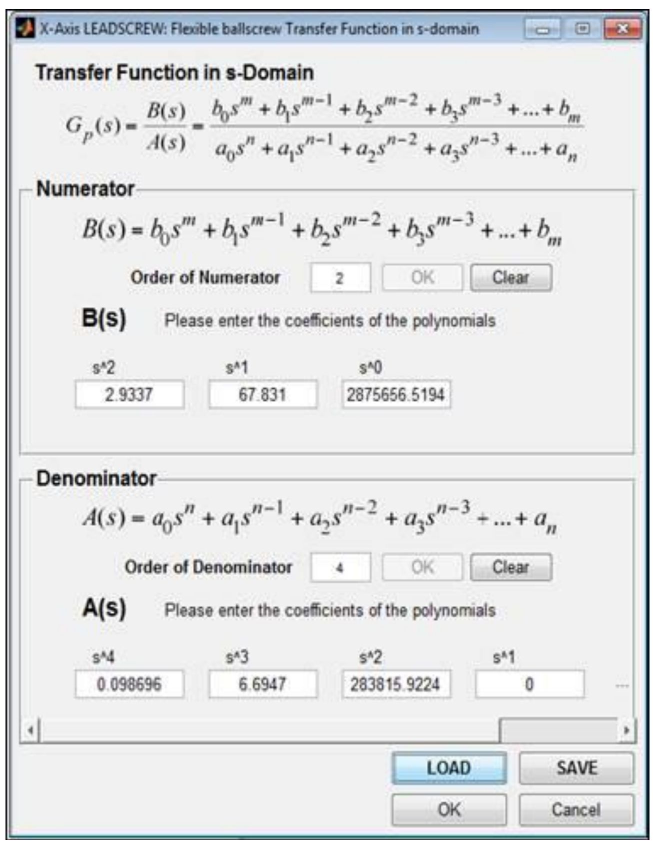
Selecting the Leadscrew Servo Drive and clicking the settings icon, you can open the interface of **Leadscrew Drive Parameters**.





After opening the interface of **Leadscrew Drive Parameters,** you should check **Flexible ball screw** and click the **settings** button in the **Dynamic Loads** section to open the Interface for loading the flexible ball screw transfer function.


X-Axis LEADSCREW: Flexible ballscrew Transfer Function in s-domain
Transfer Function in s-Domain
Numerator
Order of Numerator
OK
Clear
B(s)
Please enter the coefficients of the polynomials
Denominator
Order of Denominator
OK
Clear
A(s)
Please enter the coefficients of the polynomials
LOAD
SAVE


X-Axis LEADSCREW: Flexible ballscrew Transfer Function in s-domain
Transfer Function in s-Domain
Numerator
Order of Numerator
2
OK
Clear
B(s)
Please enter the coefficients of the polynomials
s^2
s^1
s^0
2.9337
67.831
2875656.5194
Denominator
Order of Denominator
4
OK
Clear
A(s)
Please enter the coefficients of the polynomials
s^4
s^3
s^2
s^1
0.098696
6.6947
283815.9224
0
LOAD
SAVE
OK
Cancel

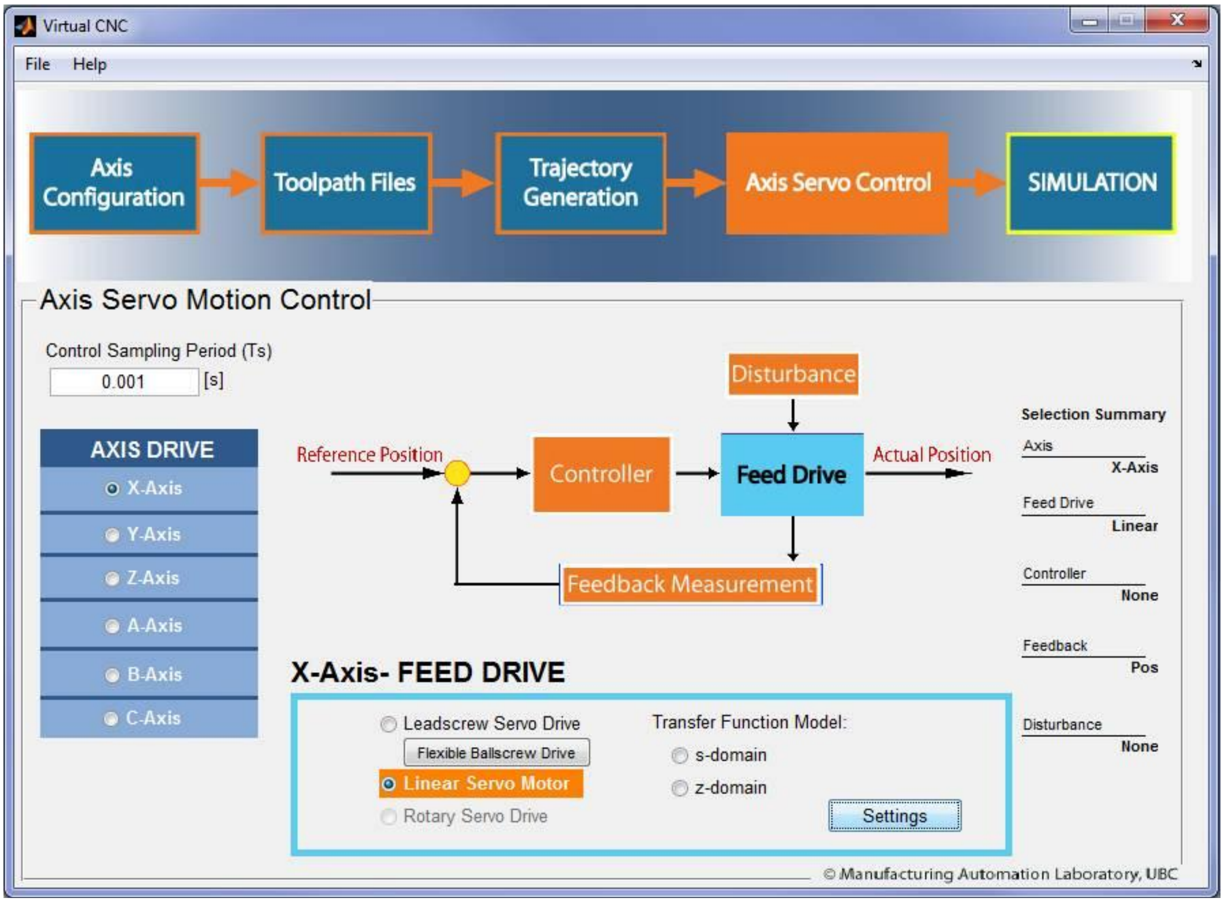
Click the **LOAD** button to select and open the tf file which was exported before as the transfer function of the flexible ball screw drive model.

After loading the exported flexible ball screw transfer function, you can see the detail information of the flexible ball screw transfer function, including the numerator, order of numerator, denominator, and order of denominator of the flexible ball screw transfer function.

After clicking the **OK** button you finish importing the flexible ball screw transfer function.

1.5.3 Linear Servo Motor Configuration

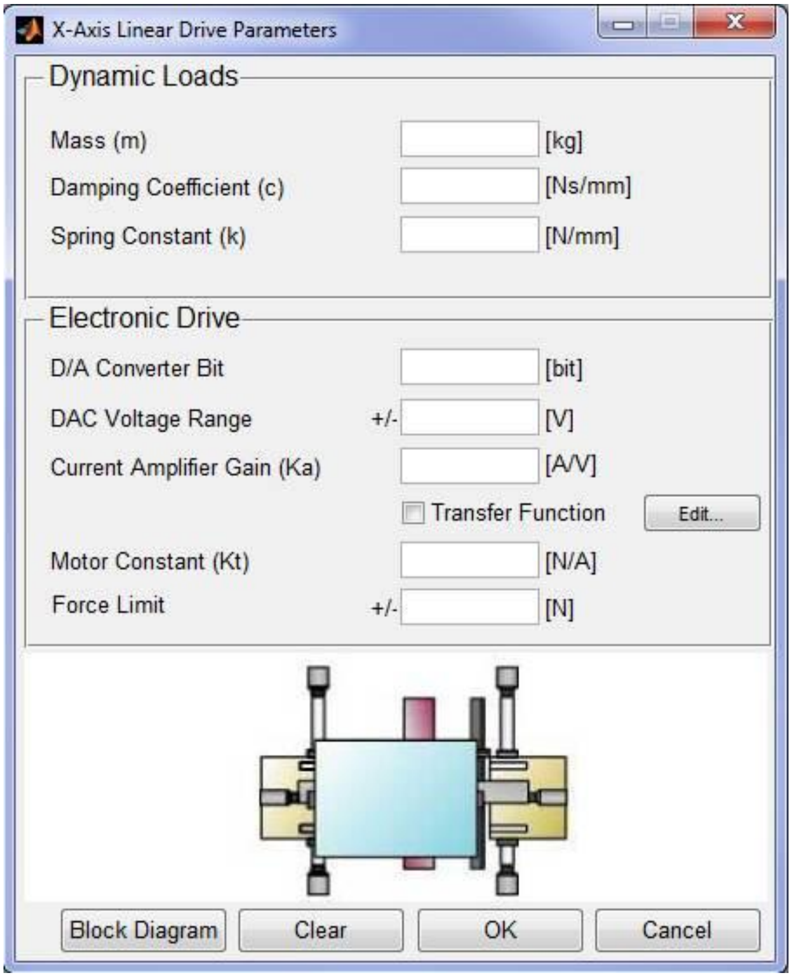
Click the **Feed Drive** icon in the Axis Servo Drive module, and when the **Feed Drive** icon is highlighting, select the **Linear Servo Motor** radial button and click the **Settings** button.

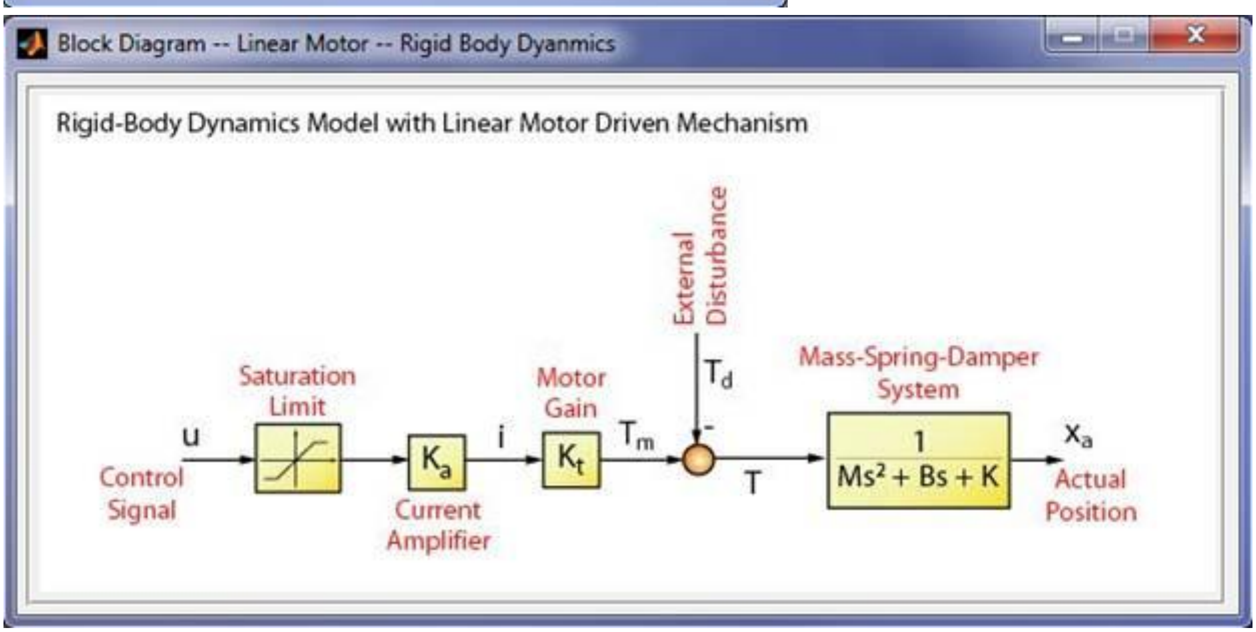


This opens the interface of **Linear Drive Parameters**.

Two sections of the parameters for the linear motor drive should be set up properly: **Dynamic Loads** and **Electronic Drive**.

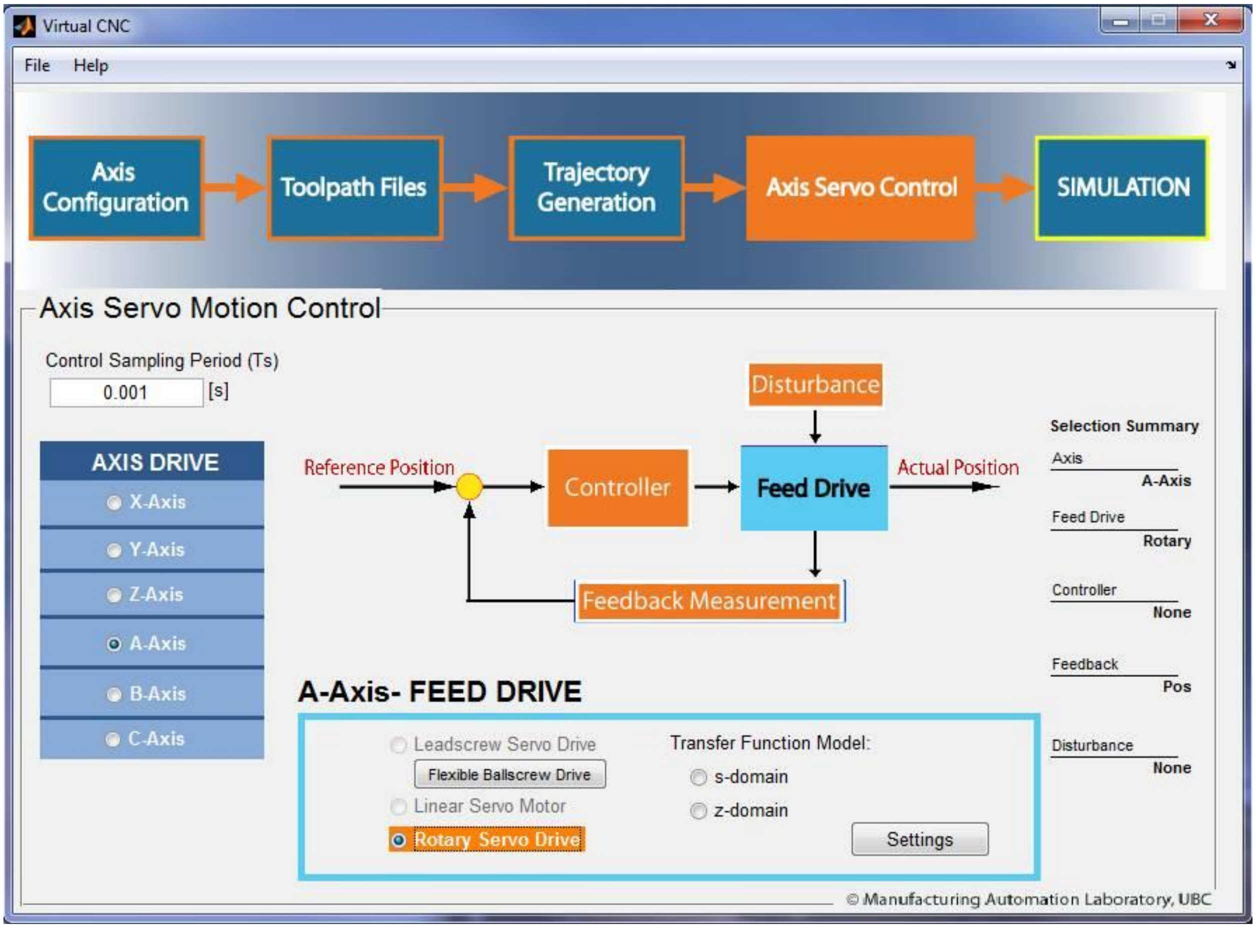
By clicking the **Block Diagram** button on the bottom you can see the block diagram structure of Rigid-Body Dynamics Model with Linear Motor Driven mechanism.


X-Axis Linear Drive Parameters
Dynamic Loads
Mass (m) [kg]
Damping Coefficient (c) [Ns/mm]
Spring Constant (k) [N/mm]
Electronic Drive
D/A Converter Bit [bit]
DAC Voltage Range +/- [V]
Current Amplifier Gain (Ka) [A/V]
Transfer Function
Edit...
Motor Constant (Kt) [N/A]
Force Limit +/- [N]
Block Diagram
Clear
OK
Cancel


Block Diagram -- Linear Motor -- Rigid Body Dyanmics
Rigid-Body Dynamics Model with Linear Motor Driven Mechanism
External Disturbance
T_d
Saturation Limit
Motor Gain
Mass-Spring-Damper System
u
K_a
i
K_t
T_m
T
$\frac{1}{Ms^2 + Bs + K}$
x_a
Control Signal
Current Amplifier
Actual Position

1.5.4 Rotary Servo Drive Configuration

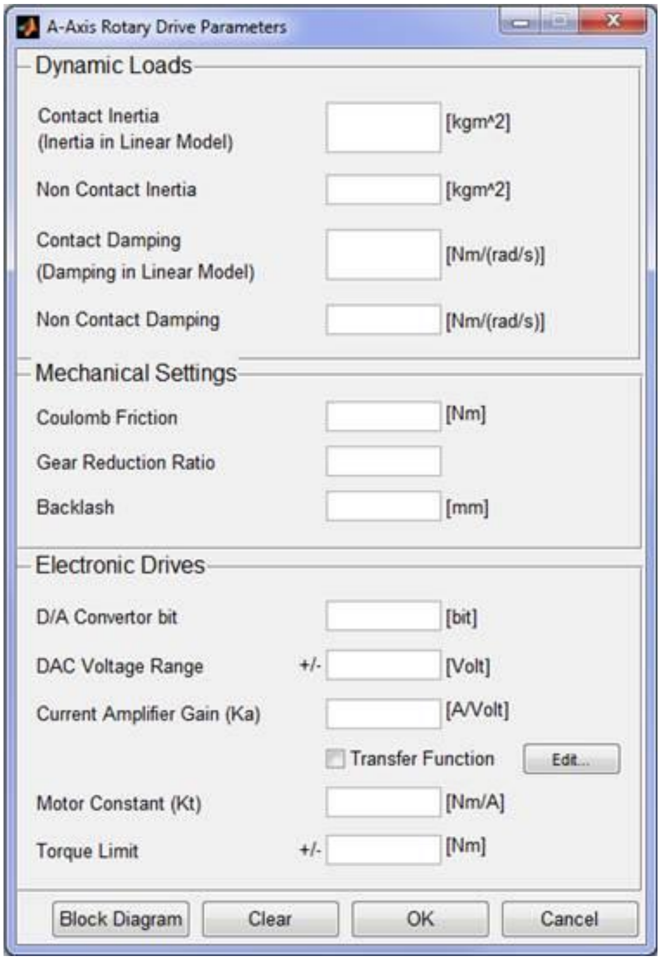
Click the **Feed Drive** icon in the Axis Servo Drive module, and when the **Feed Drive** icon is highlighting, select the **Rotary Servo Drive** radial button and click the **Settings** button.

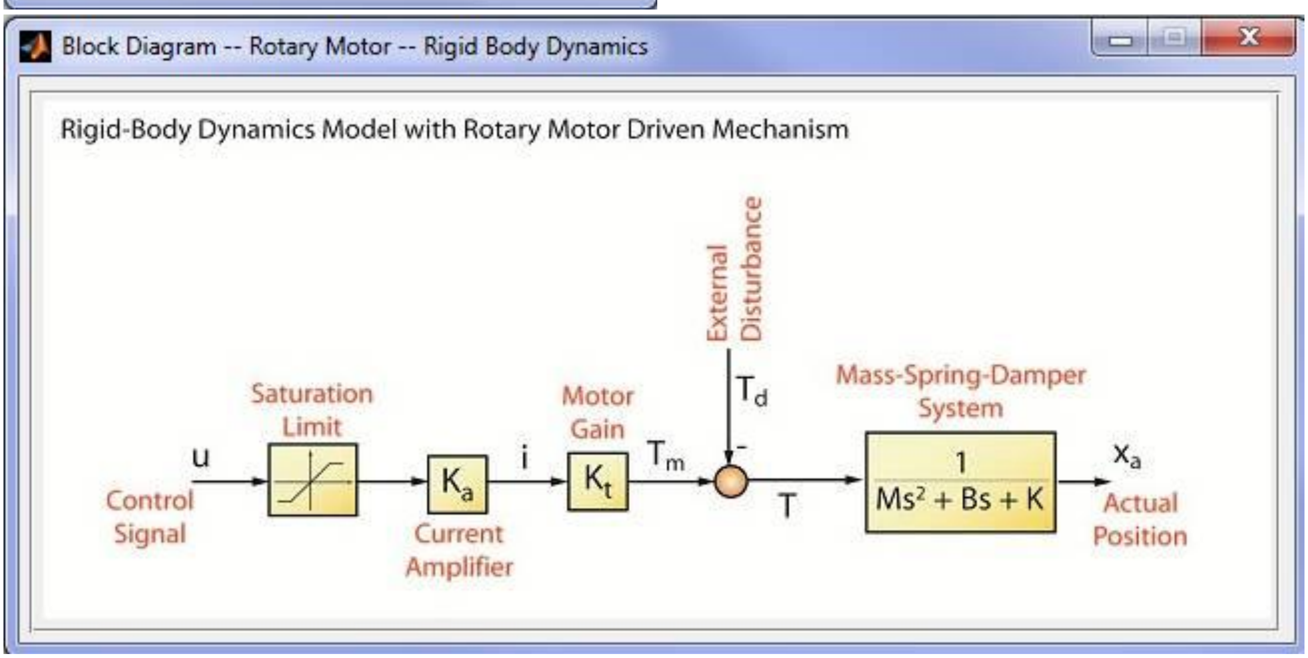


This opens the interface of **Rotary Drive Parameters**.

Three sections of the parameters for the rotary drive should be set up properly: **Dynamic Loads**, **Mechanical Settings** and **Electronic Drive**.

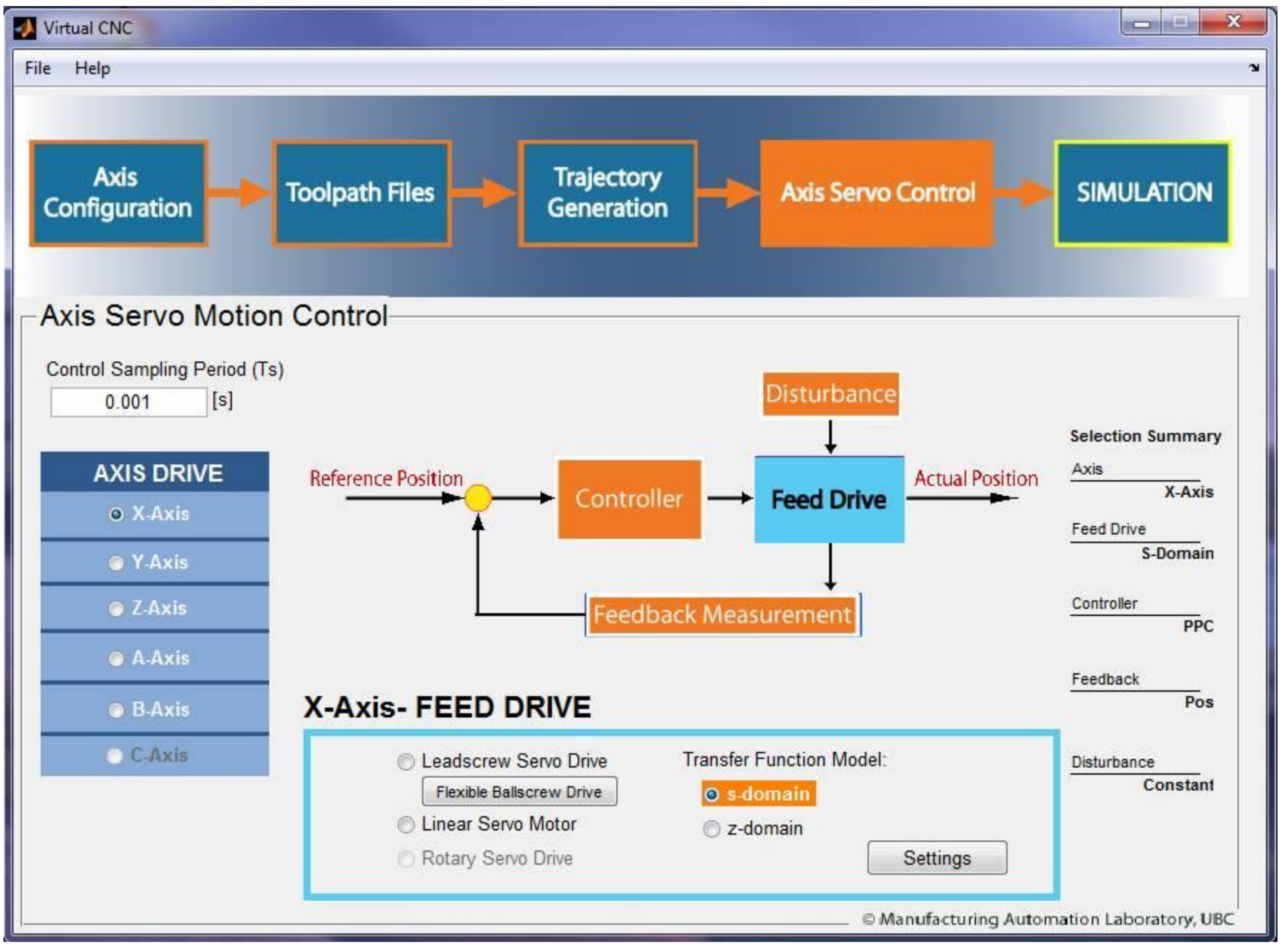
By clicking the **Block Diagram** button on the bottom you can see the block diagram structure of Rigid-Body Dynamics Model with Rotary Motor Driven mechanism.

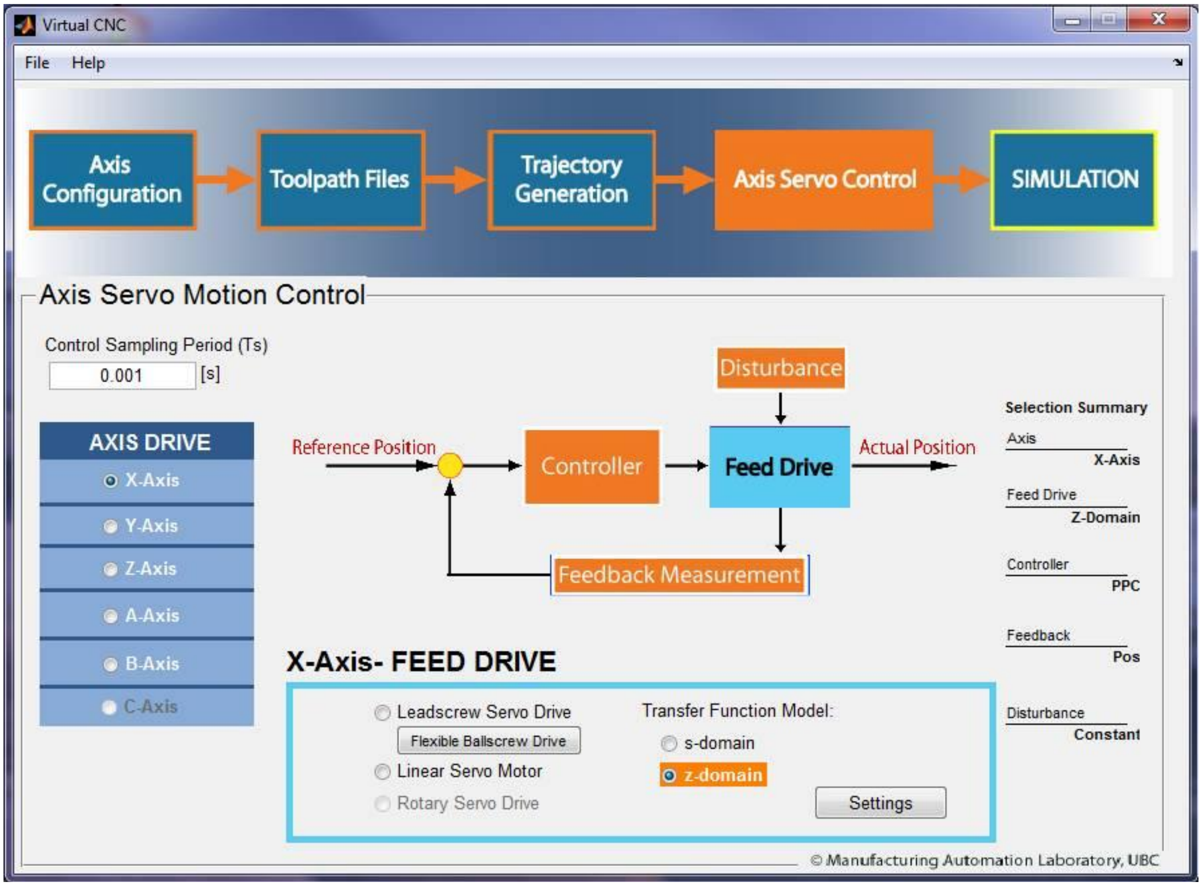

A-Axis Rotary Drive Parameters
Dynamic Loads
Contact Inertia
(Inertia in Linear Model)
[kgm^2]
Non Contact Inertia
[kgm^2]
Contact Damping
(Damping in Linear Model)
[Nm/(rad/s)]
Non Contact Damping
[Nm/(rad/s)]
Mechanical Settings
Coulomb Friction
[Nm]
Gear Reduction Ratio
Backlash
[mm]
Electronic Drives
D/A Convertor bit
[bit]
DAC Voltage Range
+/-
[Volt]
Current Amplifier Gain (Ka)
[A/Volt]
Transfer Function
Edit...
Motor Constant (Kt)
[Nm/A]
Torque Limit
+/-
[Nm]
Block Diagram
Clear
OK
Cancel


Block Diagram -- Rotary Motor -- Rigid Body Dynamics
Rigid-Body Dynamics Model with Rotary Motor Driven Mechanism
External Disturbance
Td
Saturation Limit
Motor Gain
Mass-Spring-Damper System
u
Control Signal
Ka
Current Amplifier
i
Kt
Tm
T
1
Ms² + Bs + K
xa
Actual Position

1.5.5 Transfer Function Model (s-domain and z-domain) Configuration

Click the **Feed Drive** icon in the Axis Servo Drive module, and when the **Feed Drive** icon is highlighting, select one radial button below the **Transfer Function Model,** either **s-domain** or **z-domain** and click the **Settings** button.

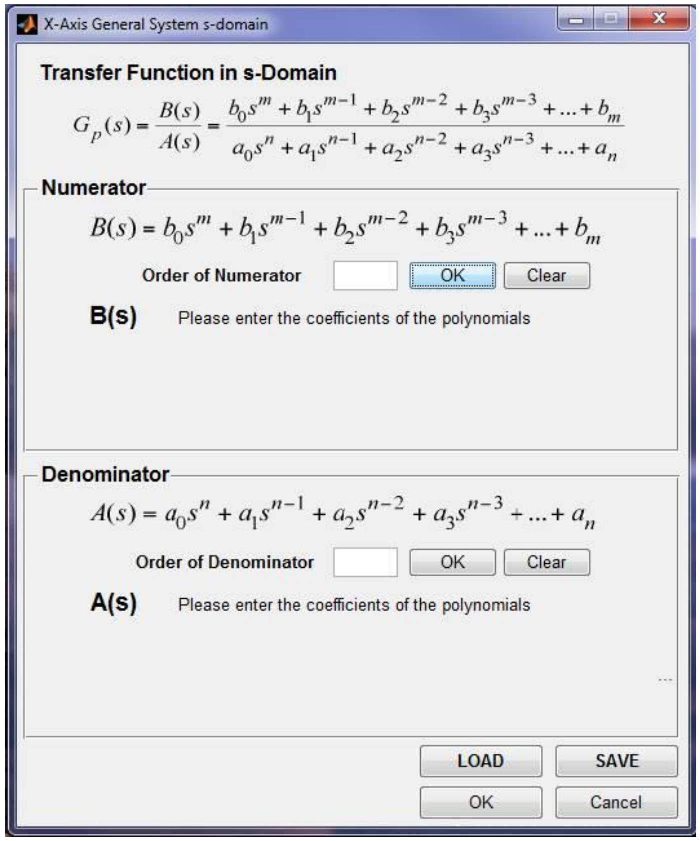


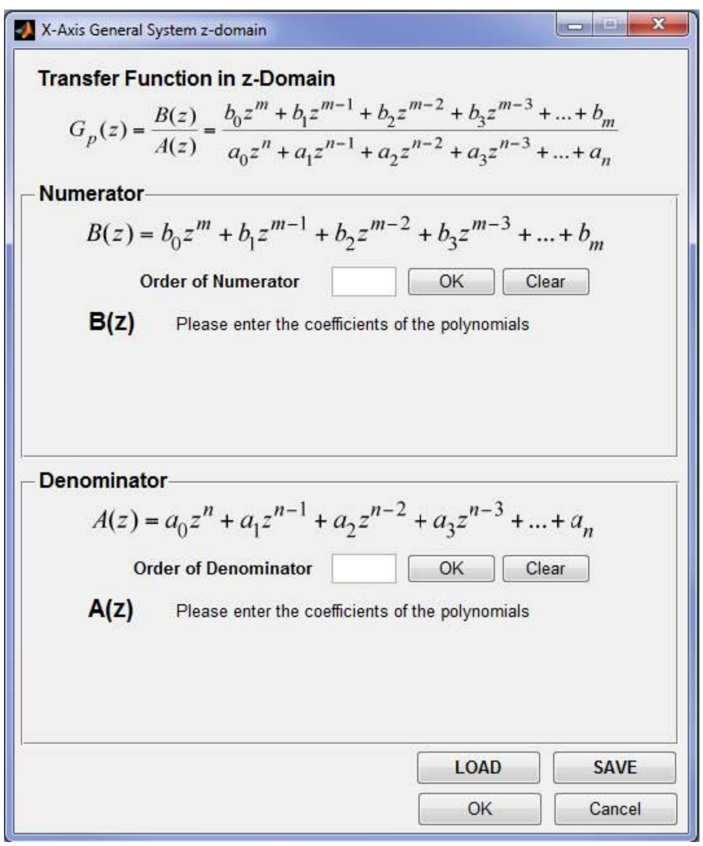


This opens the interface of the transfer function configuration.

You can input the transfer function parameters of the feed drive in the s-domain or z-domain.

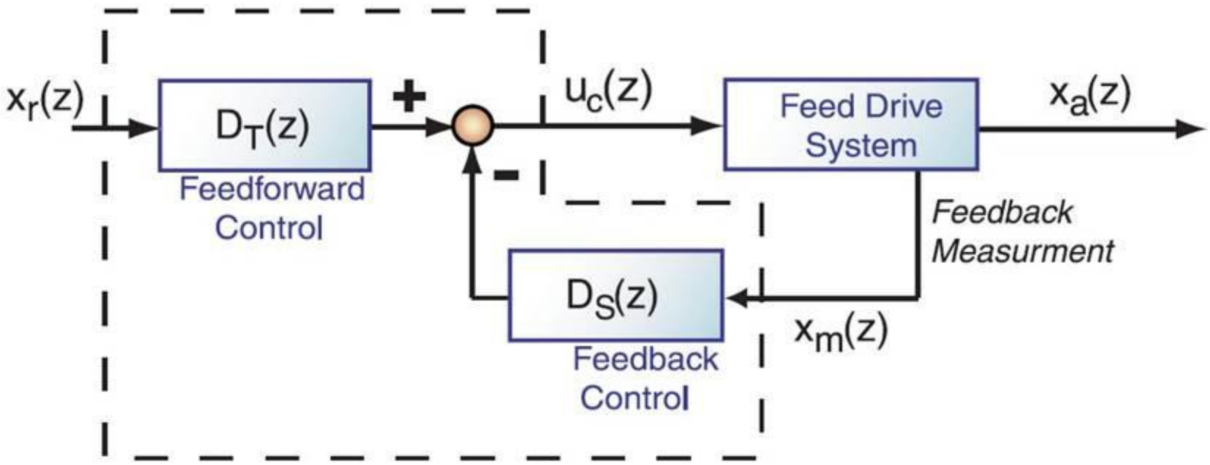
The parameters include the polynomial orders and coefficients of the numerator and denominator.


X-Axis General System s-domain
Transfer Function in s-Domain
$G_p(s)=\frac{B(s)}{A(s)}=\frac{b_0s^m+b_1s^{m-1}+b_2s^{m-2}+b_3s^{m-3}+...+b_m}{a_0s^n+a_1s^{n-1}+a_2s^{n-2}+a_3s^{n-3}+...+a_n}$
Numerator
$B(s)=b_0s^m+b_1s^{m-1}+b_2s^{m-2}+b_3s^{m-3}+...+b_m$
Order of Numerator
OK
Clear
B(s)
Please enter the coefficients of the polynomials
Denominator
$A(s)=a_0s^n+a_1s^{n-1}+a_2s^{n-2}+a_3s^{n-3}+...+a_n$
Order of Denominator
OK
Clear
A(s)
Please enter the coefficients of the polynomials
LOAD
SAVE
OK
Cancel


X-Axis General System z-domain
Transfer Function in z-Domain
$G_p(z)=\frac{B(z)}{A(z)}=\frac{b_0z^m+b_1z^{m-1}+b_2z^{m-2}+b_3z^{m-3}+...+b_m}{a_0z^n+a_1z^{n-1}+a_2z^{n-2}+a_3z^{n-3}+...+a_n}$
Numerator
$B(z)=b_0z^m+b_1z^{m-1}+b_2z^{m-2}+b_3z^{m-3}+...+b_m$
Order of Numerator
OK
Clear
B(z)
Please enter the coefficients of the polynomials
Denominator
$A(z)=a_0z^n+a_1z^{n-1}+a_2z^{n-2}+a_3z^{n-3}+...+a_n$
Order of Denominator
OK
Clear
A(z)
Please enter the coefficients of the polynomials
LOAD
SAVE
OK
Cancel

1.5.6 Controller Configuration

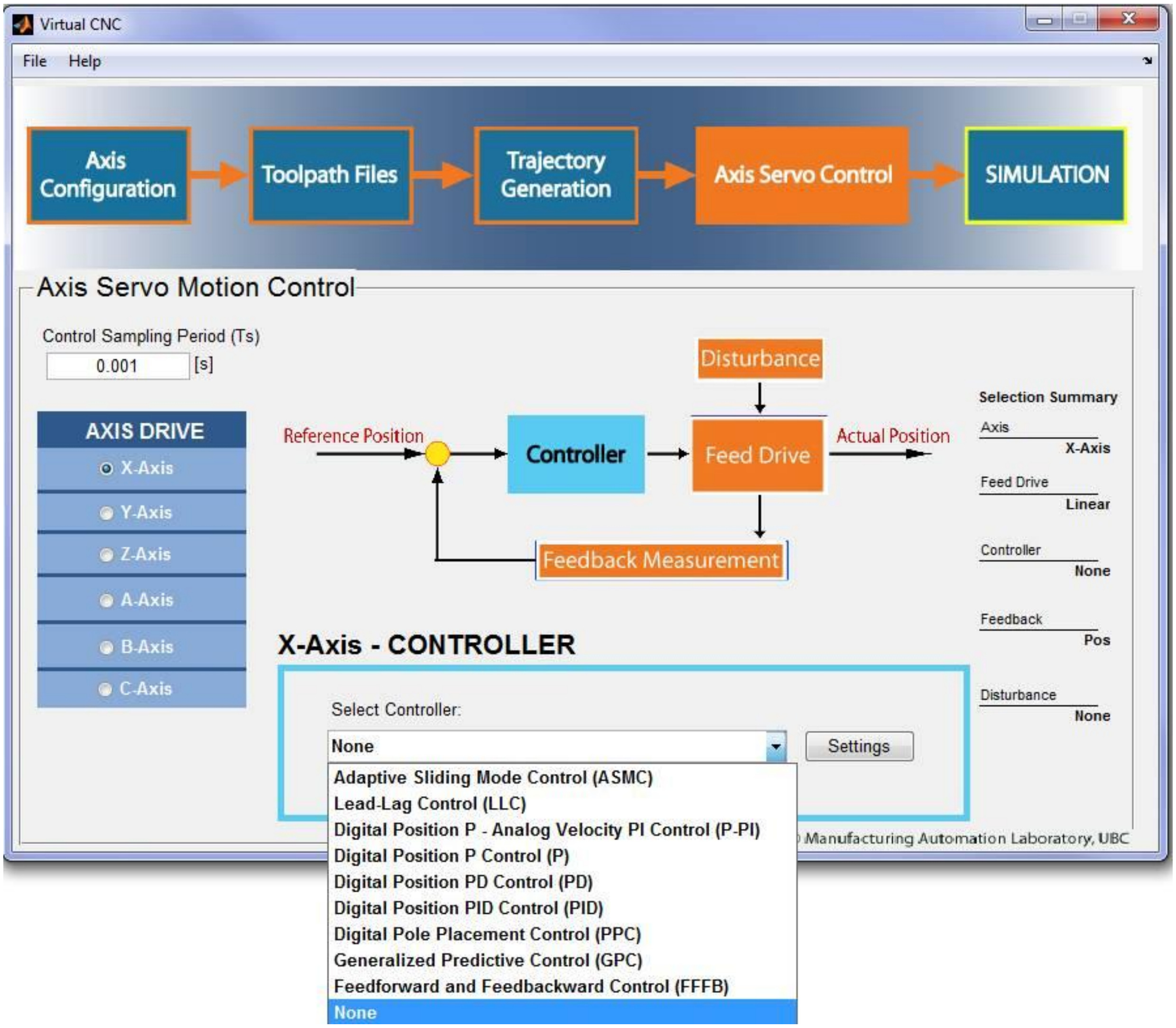
There are a significant number of control laws, which can be implemented in CNC systems. Typically, any axis control law has two components: the feedforward part which processed the reference position commands, and the feedback part that shapes the measured states such as position, velocity and acceleration to stabilize the closed loop dynamics. The below figure is the axis control law in a standard form.



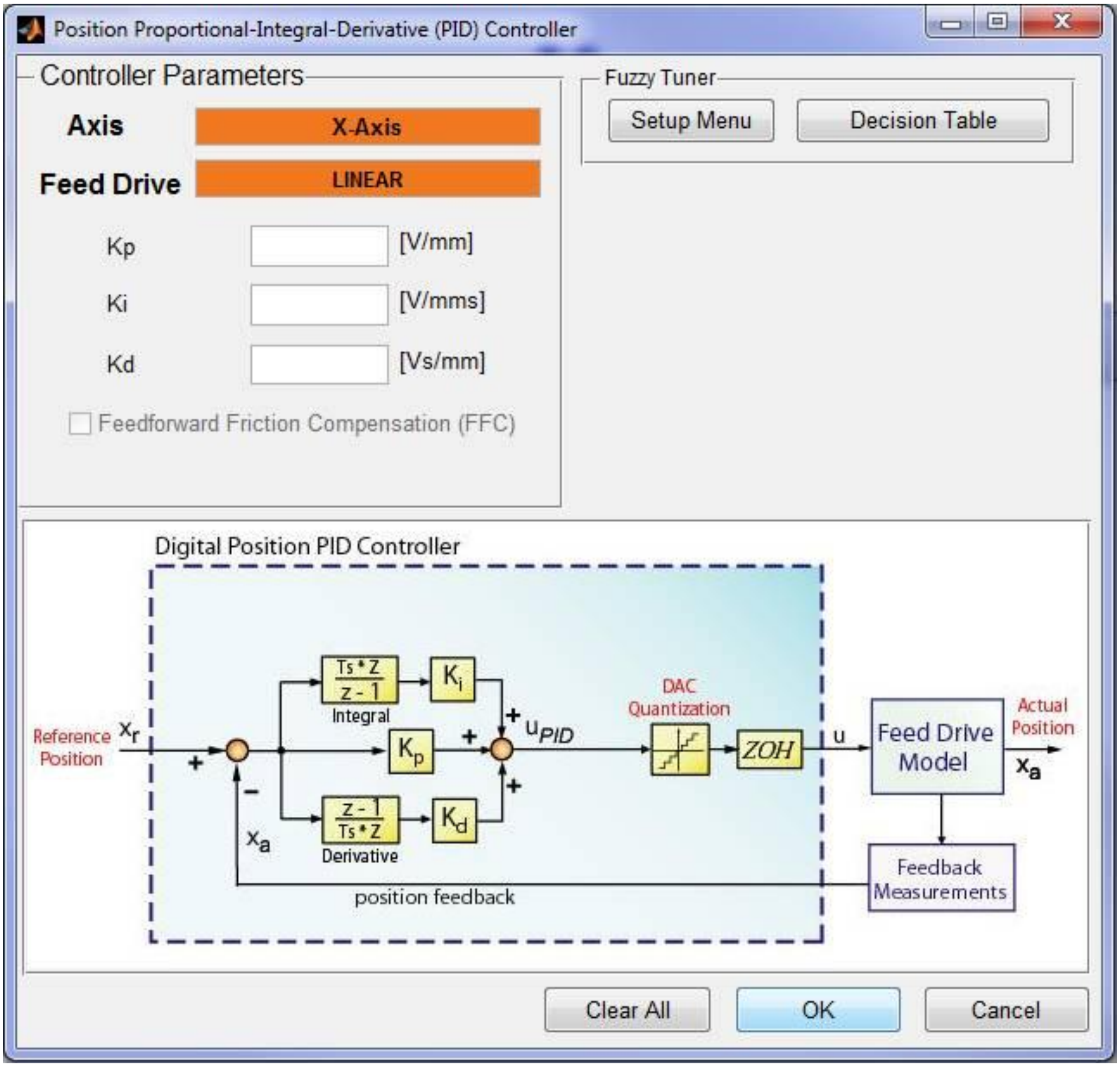
$D_T(Z)$ and $D_S(Z)$ are the matrices corresponding to the feedforward and feedback transfer functions respectively, in the discrete time domain. $X_r(k)$ is the reference axis command state vector and $X_m(k)$ is the axis measurement state vector.

Virtual CNC has a number of user reconfigurable control law, which have all been experimentally proven on the open CNC system. The conventional control laws include: Adaptive Sliding Mode Control (**ASMC**), Lead-Lag Control (**LLC**), Digital Position P-Analog Velocity PI control (**P-PI**), Digital Position P Control (**P**), Digital Position PD Control (**PD**), Digital Position PID Control (**PID**), Digital Pole Placement Control (**PPC**), Generalized Predictive Control (**GPC**) and Feed Forward and Feedback Control (**FFFB**).

Click the **Controller** icon in the Axis Servo Drive module, and when the **Controller** icon is highlighting, you can select different types of controllers by clicking the pop-up menu.

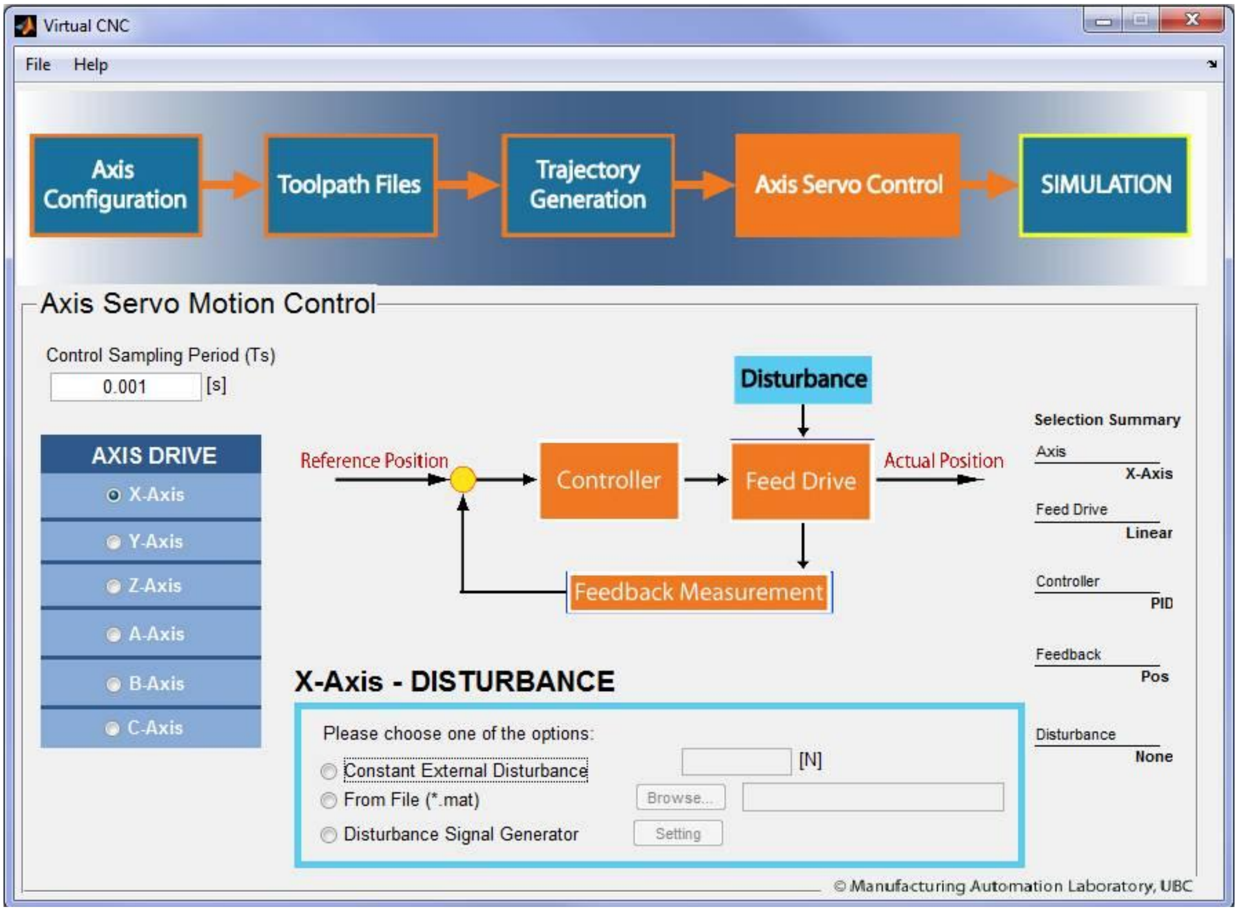


Using the Digital Position PID Control (**PID**) as an example, by selecting **PID** option and clicking **Settings** button, you can set up the **PID** controller parameters $\mathbf{K_p}$, $\mathbf{K_i}$ and $\mathbf{K_d}$.


Position Proportional-Integral-Derivative (PID) Controller
Controller Parameters
Axis
X-Axis
Feed Drive
LINEAR
Kp
[V/mm]
Ki
[V/mms]
Kd
[Vs/mm]
Feedforward Friction Compensation (FFC)
Fuzzy Tuner
Setup Menu
Decision Table
Digital Position PID Controller
Reference Position
Integral
Derivative
DAC Quantization
ZOH
Feed Drive Model
Actual Position
Feedback Measurements
position feedback
Clear All
OK
Cancel

1.5.6 Disturbance Configuration

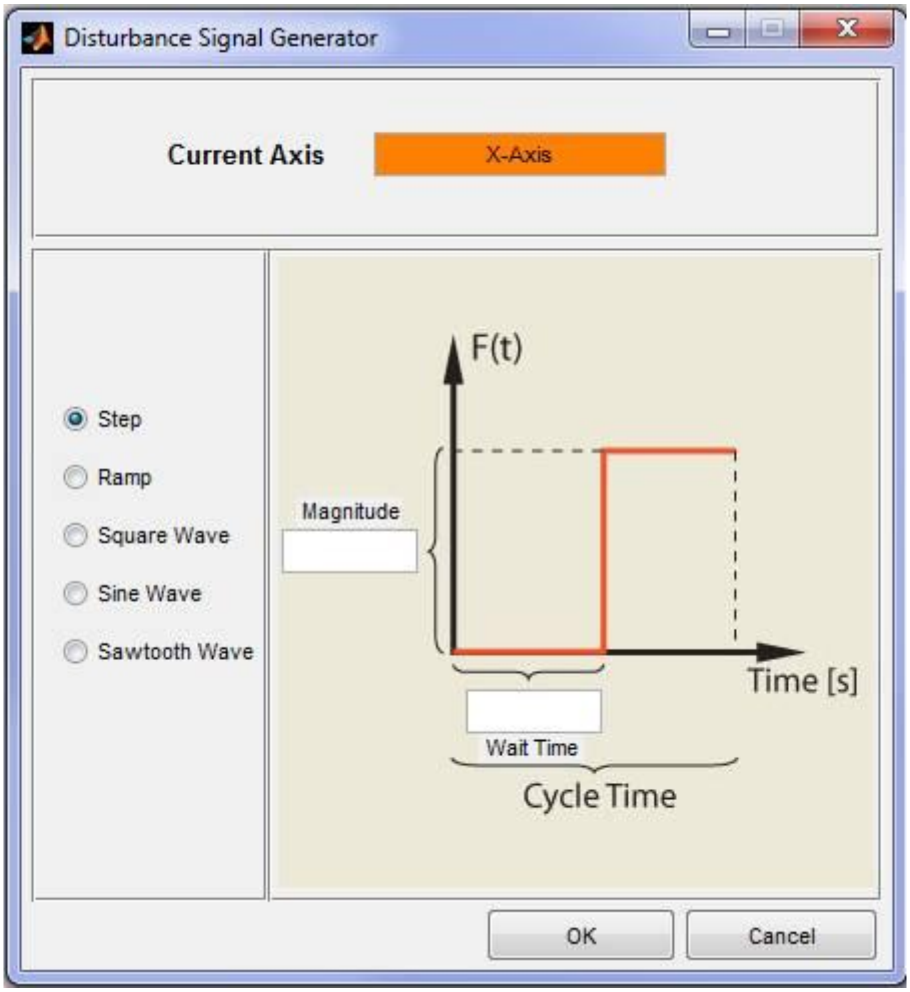
Click the **Disturbance** icon in the Axis Servo Drive module, and when the **Disturbance** icon is highlighting, you can choose one type of the three options of disturbance to the feed drive. The three options are **Constant External Disturbance, From File** and **Disturbance Signal Generator**.



If you select **Constant External Disturbance** option, you should define a value (Unit: [N]) of the constant external disturbance.

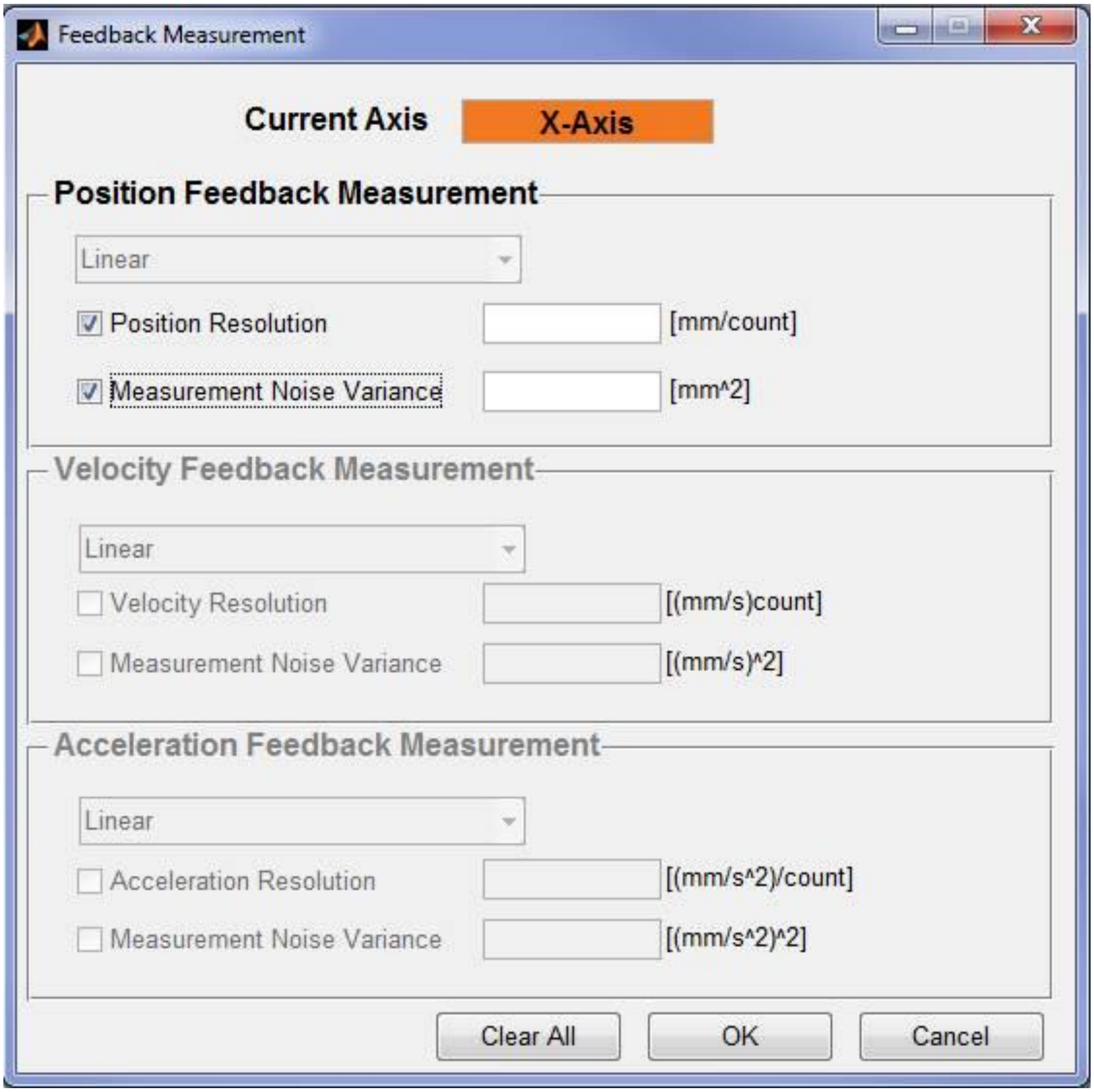
If you select **From File** Option, you should load a file after clicking the Browse button.

If you select **Disturbance Signal Generator** option, after clicking the Settings button you can open the interface below. Then you can define the disturbance signal.



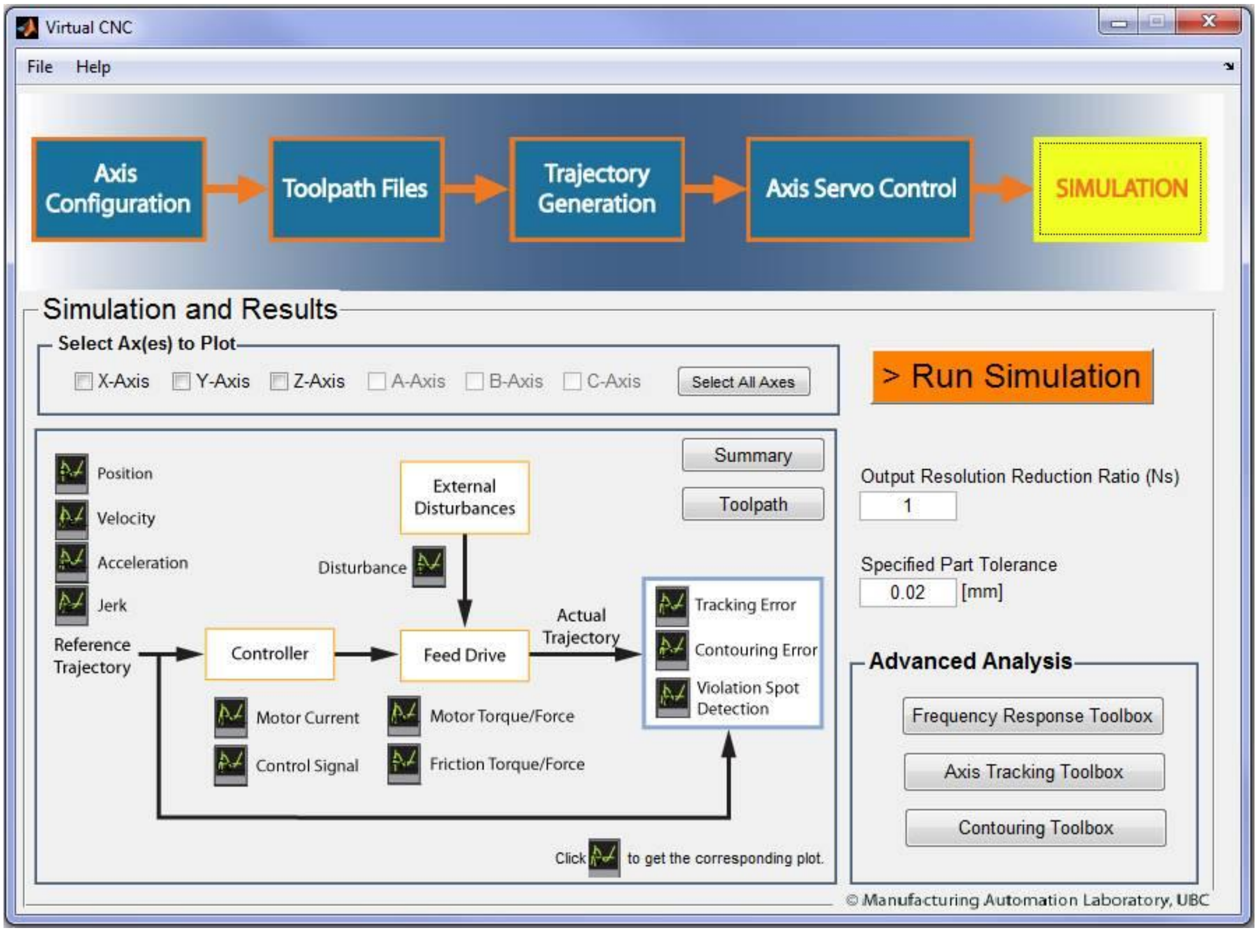
1.5.7 Feedback Measurement Configuration

Click the **Feedback Measurement** icon in the Axis Servo Drive module to open the interface of **Feedback Measurement.** Then choose one type of the three options of feedback measurement to the feed drive. The three options are: **position, velocity and acceleration.**



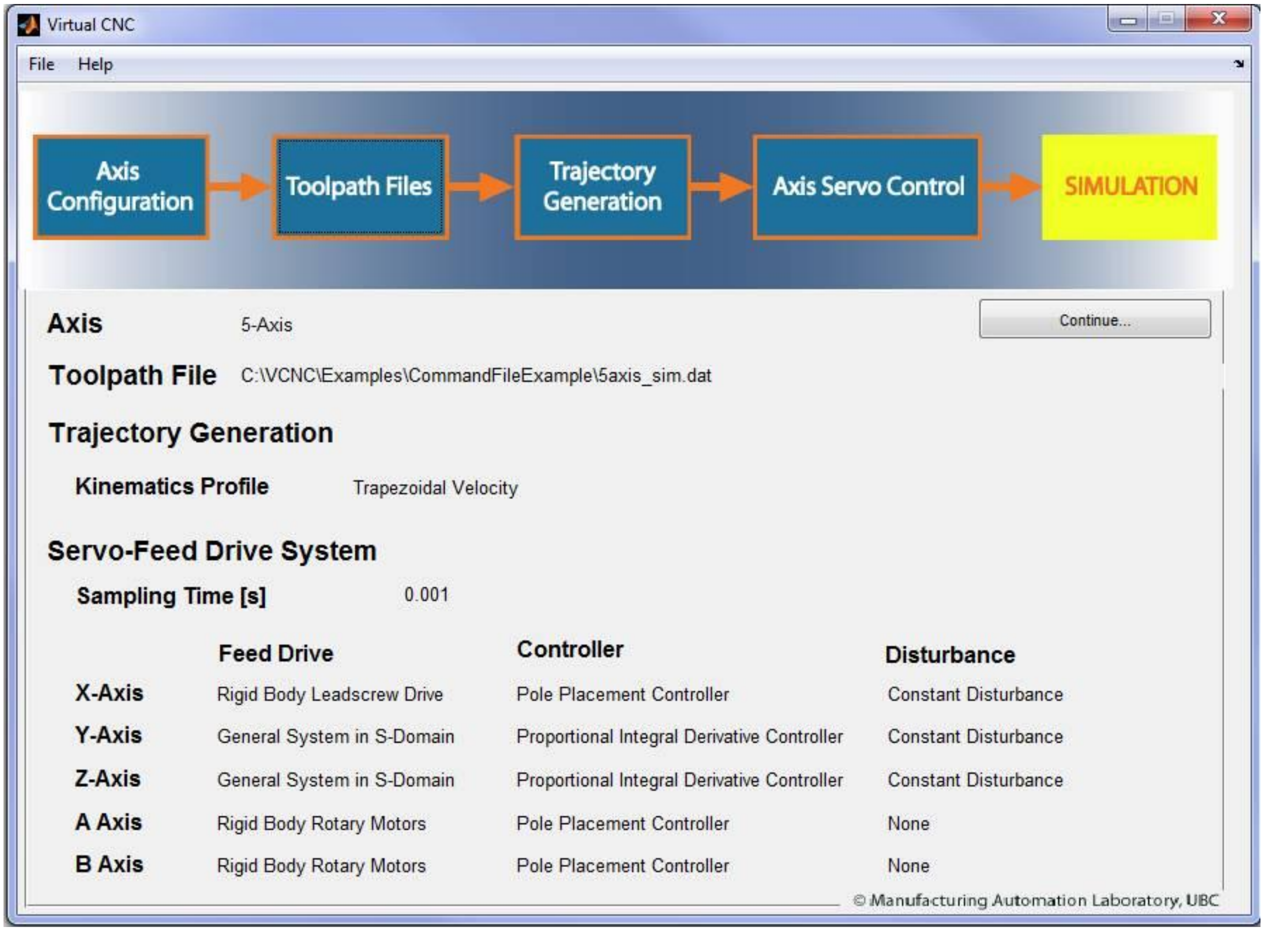
1.6 Simulation Configuration

Now you have finished all configurations. In the **Simulation** Module, you will see the simulation results by running simulation. First, you should define the **output resolution reduction ratio** and **specify part tolerance**.



To proceed to the Simulation Summary, click the **Run Simulation** button and open the interface Simulation Summary, which shows a summary of the machine setup including the axis configuration, tool path file, trajectory generation and feed drive system.

Click the **Continue** button and the system will start the simulation and show the simulation results.



After the simulation you can **select the axes** to check the simulation results and click the icons  in the **Simulation and Results** Toolbox to get the corresponding plot.

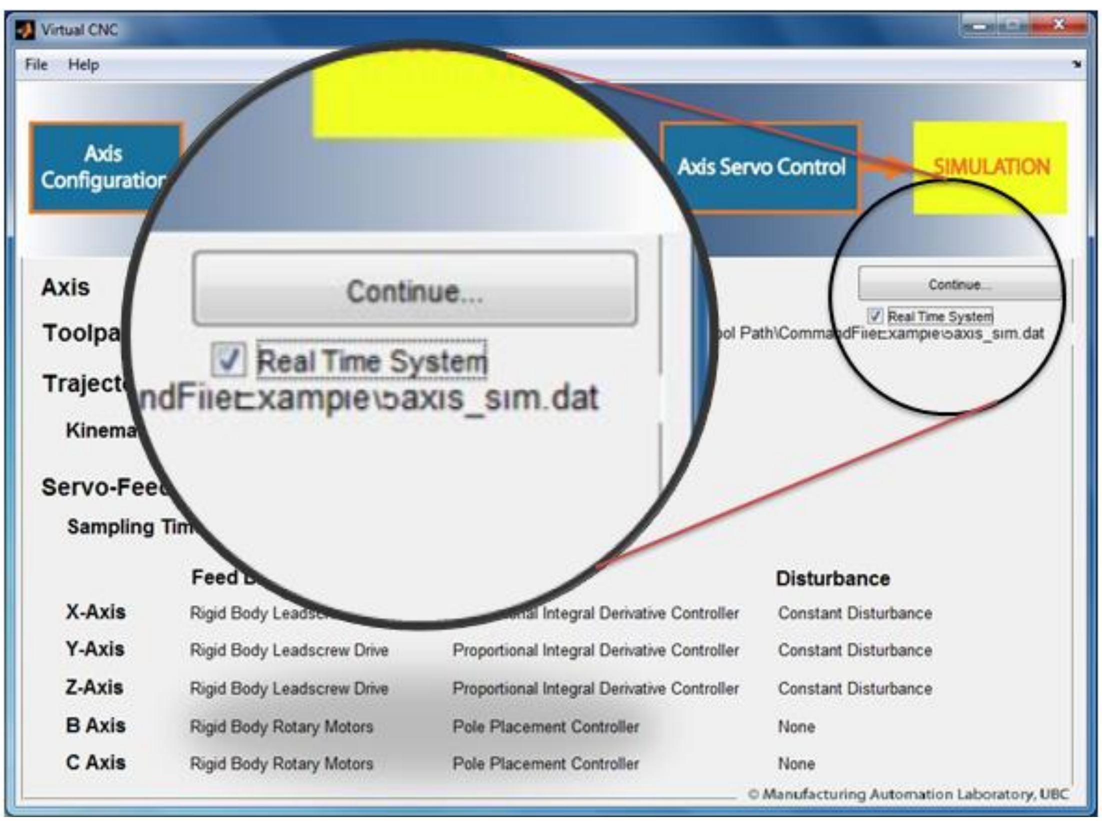
You also can use the **Advanced Analysis Toolbox** to gain the detail information about the **Frequency Response**, **Axis Tracking** and **Contouring error**.

1.6.1 Virtual CNC Real Time Implementation Quick Start Guide

A sample application of the real time implementation will be shown below for a 3 axis Fadal machining center.

Step 1: Loading a Model
Open VCNC and load the example file located in Virtual CNC Examples/Ex01_Kinematic Configurations\Ex01A_3 Axis Rigid Drive Example.vcnc. This is done by going to **File->Open** in VCNC.

Step 2: Simulating the Model
The settings within VCNC can be changed, however the default setting should work for the example. After making any changes to the system parameters the **Run Simulation** button can be pressed, located in the **Simulation** tab page. After clicking the **Run Simulate** button check the **Real Time System** checkbox, as shown below. Then click **Continue** as you regularly would for running a simulation.



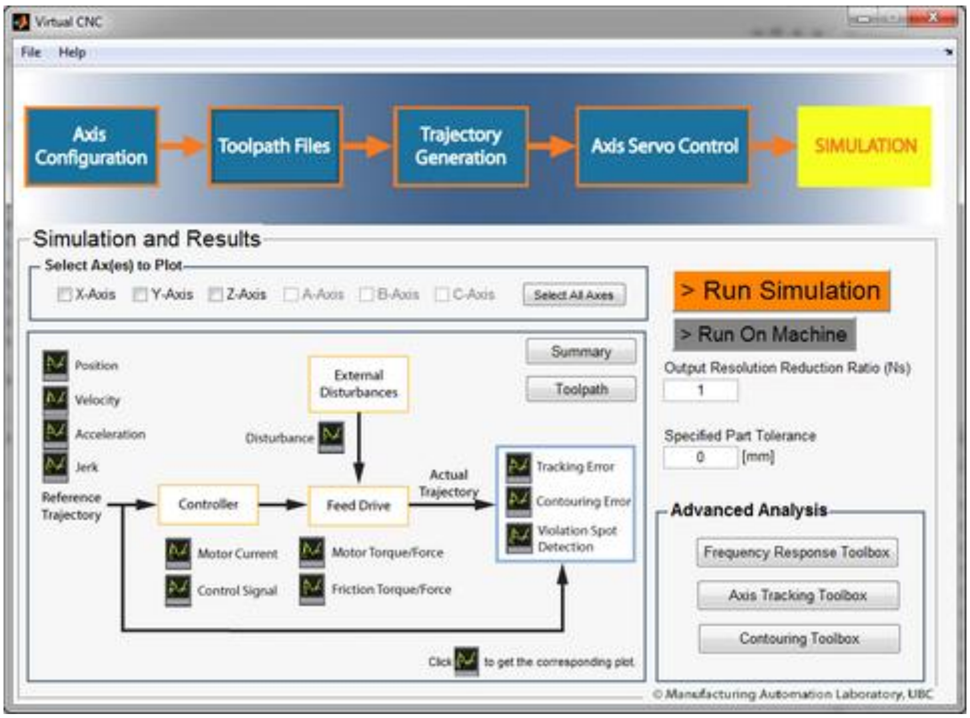
Note: If the system is to be tested on a real machine the computer running VCNC must have a dSPACE DS1103 device connected to it. This system will build the controllers and trajectory into a C-coded file that is automatically loaded to the dSPACE board. The dSPACE board needs to be connected to the machine using the connection mapping shown in the table below:

Real Time dSpace Connector Map

DS1103 Connector	Machine Connection	Description
DACH1	X-AXIS CONTROL (-10 to +10 volts)	Voltage to control axis
DACH2	Y-AXIS CONTROL (-10 to +10 volts)	Voltage to control axis
DACH3	Z-AXIS CONTROL (-10 to +10 volts)	Voltage to control axis
DACH4	A-AXIS CONTROL (-10 to +10 volts)	Voltage to control axis
DACH5	B-AXIS CONTROL (-10 to +10 volts)	Voltage to control axis
DACH6	C-AXIS CONTROL (-10 to +10 volts)	Voltage to control axis
DACH7	Spindle Control (-10 to +10 volts)	Voltage to control spindle RPM
Inc1	X-AXIS FEEDBACK	Encoder Feedback
Inc2	Y-AXIS FEEDBACK	Encoder Feedback
Inc3	Z-AXIS FEEDBACK	Encoder Feedback
Inc4	A-AXIS FEEDBACK	Encoder Feedback
Inc5	B-AXIS FEEDBACK	Encoder Feedback
Inc6	C-AXIS FEEDBACK	Encoder Feedback
Digital I/O PIN 1 (Input)	Spindle Feedback	5Volts = error, 0V = okay
Digital I/O PIN 9 (Output)	Spindle on/off	5Volts = on, 0Volts = off

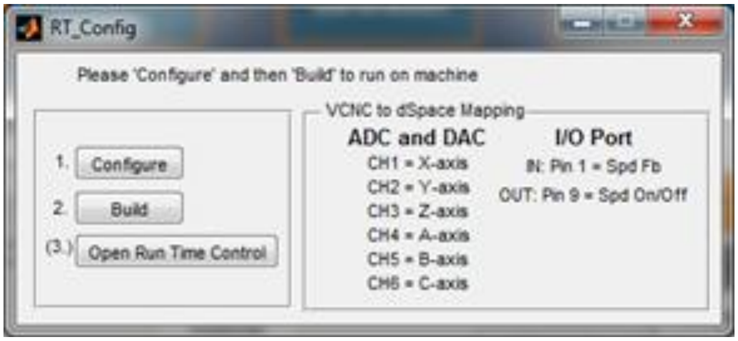
Step 3: Configuring the Real Time Build Information

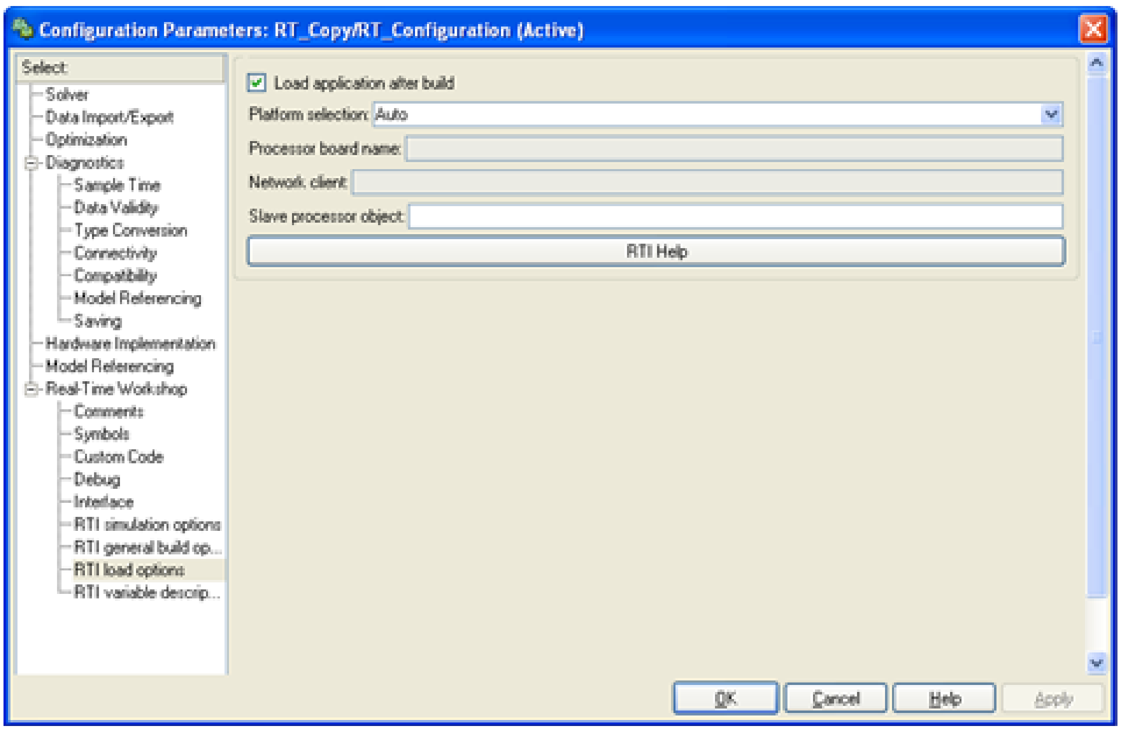
Once the simulation has been run with the **Real Time System** checkbox clicked, the **Run On Machine** button can be pressed to start the process of preparing the code for real time testing.



Step 4: Configuring Build Parameters

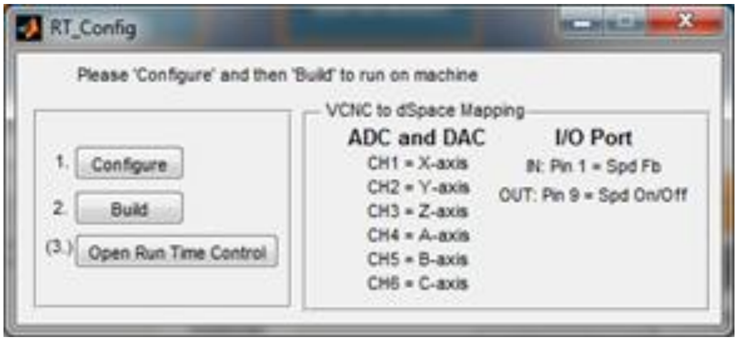
First the **Configure** button in the **RT_Config** window needs to be pressed to configure the real time build parameters. This will open the **Configuration Parameters** window. The default settings should generally be correct and the **OK** button can be pressed to confirm and return to the **RT_Config** window.

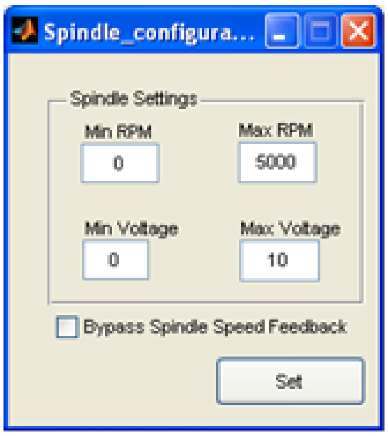




Step 5: Building the Real Time Implementation

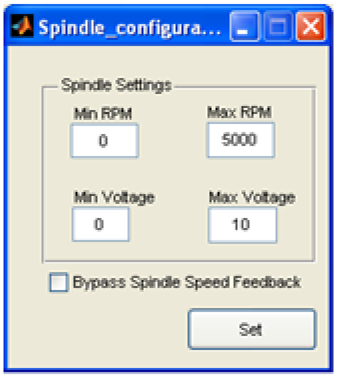
The **Build** button in the **RT_Config** window can then be pressed. The system will then build, compile, and load the C code onto the dSPACE board. Once it is complete it will open a **Spindle_Configuration** dialog window.





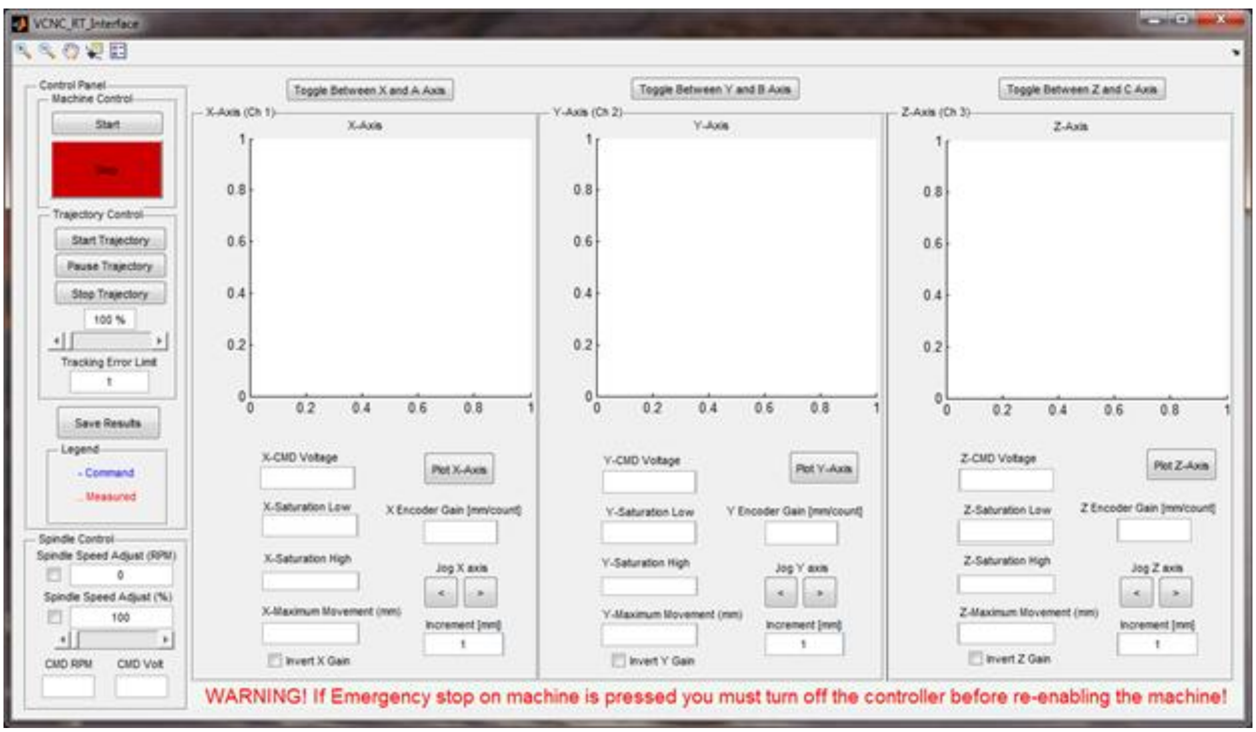
Step 6: Spindle Control Configuration

The spindle RPM is set by the dSPACE outputting a voltage. The relationship between the RPM and voltage is assumed to be linear. Therefore, the minimum and maximum RPM range of the machine is required as well as the minimum and maximum voltage that the machine is expecting for the Spindle RPM control. Linear interpolation is then automatically used to determine the required output voltage. If there is no spindle feedback available the **Bypass Spindle Speed Feedback** checkbox can be checked. This will disable the feedback and the controller will assume the spindle is operating at the requested RPM. The **Set** button can then be pressed and the real time GUI window will open (Labeled as **VCNC_RT_Interface**).



Step 7: Using the Real Time Interface to Control the Machine

The real time GUI is used to control the machine using the designed controller and trajectory. The table included below explains the operation of each button.



Real Time GUI Description

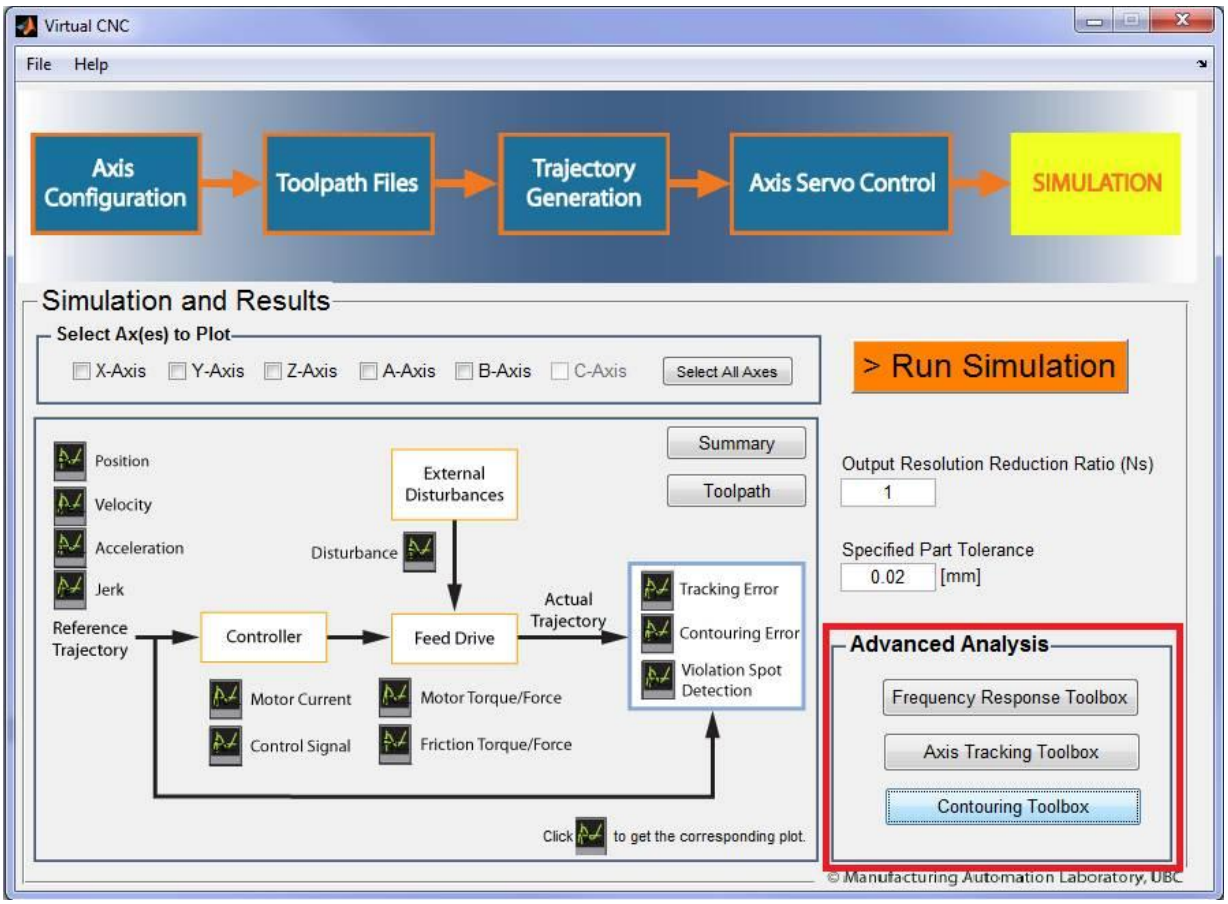
Graphical User Interface Function Name	Function Description
Machine Control - Start	Starts the controllers running on the machine
Machine Control - Stop	Stops the controllers therefore stopping the machine via software
Trajectory Control Start Trajectory	Start or Resume the programmed trajectory
Trajectory Control Pause Trajectory	Pause the programmed trajectory at its current position WARNING: This will stop the machine in its current position suddenly, causing a large deceleration and jerk
Trajectory Control Stop Trajectory	This stops the trajectory, similar to Pause, however it resets everything so that it will start from the beginning next time
Trajectory Control Feed Rate Override (below Stop Trajectory)	Allows the trajectory speed to be adjusted from 0 to 200% of original trajectory speed (100% is original speed)
Trajectory Control Tracking Error	Safety to limit Tracking Error, if individual axis exceeds limit the output voltage is shut off
Save Results	Save data collected during Trajectory execution (output formats are csv and mat)
Spindle Control Spindle Speed Adjust(RPM)	If this option is selected it adds the entered spindle RPM to the originally commanded RPM (Can be negative)
Spindle Control Spindle Speed Adjust(%)	If this option is selected it scales the originally commanded RPM by the entered value (0 to 200%)
Spindle Control CMD RPM	Displays the currently commanded RPM
Spindle Control CMD Volt	Displays the voltage currently sent to the machine for RPM control

Axis Control Toggle Between	Allows the user to switch between the axis (i.e. X or A, Y or B, Z or C)
Axis Control CMD Voltage	Displays the current voltage being sent to the drive amp
Axis Control Saturation Low	Sets minimum output voltage that can be sent to drive amp
Axis Control Saturation High	Sets maximum output voltage that can be sent to drive amp
Axis Control Maximum Movement (mm)	Sets absolute maximum movement that that axis can move from starting position, when exceeded output is set to 0 volt
Axis Control Invert Gain	Set the axis feedback gain to be inverted WARNING: Do not switch during operation, unstable behavior will occur!
Axis Control Plot Axis	Shows a detailed plot of that particular axis
Axis Control Encoder Gain[mm/count]	Displays the current encoder gain [mm/count], can also be used to set a new encoder gain
Axis Control Jog axis	Moves the axis using the controller amount specified by the Increment box
Axis Control Increment[mm]	Sets the jog increment (unit is mm)

1.6.3 Advanced Analysis Toolbox

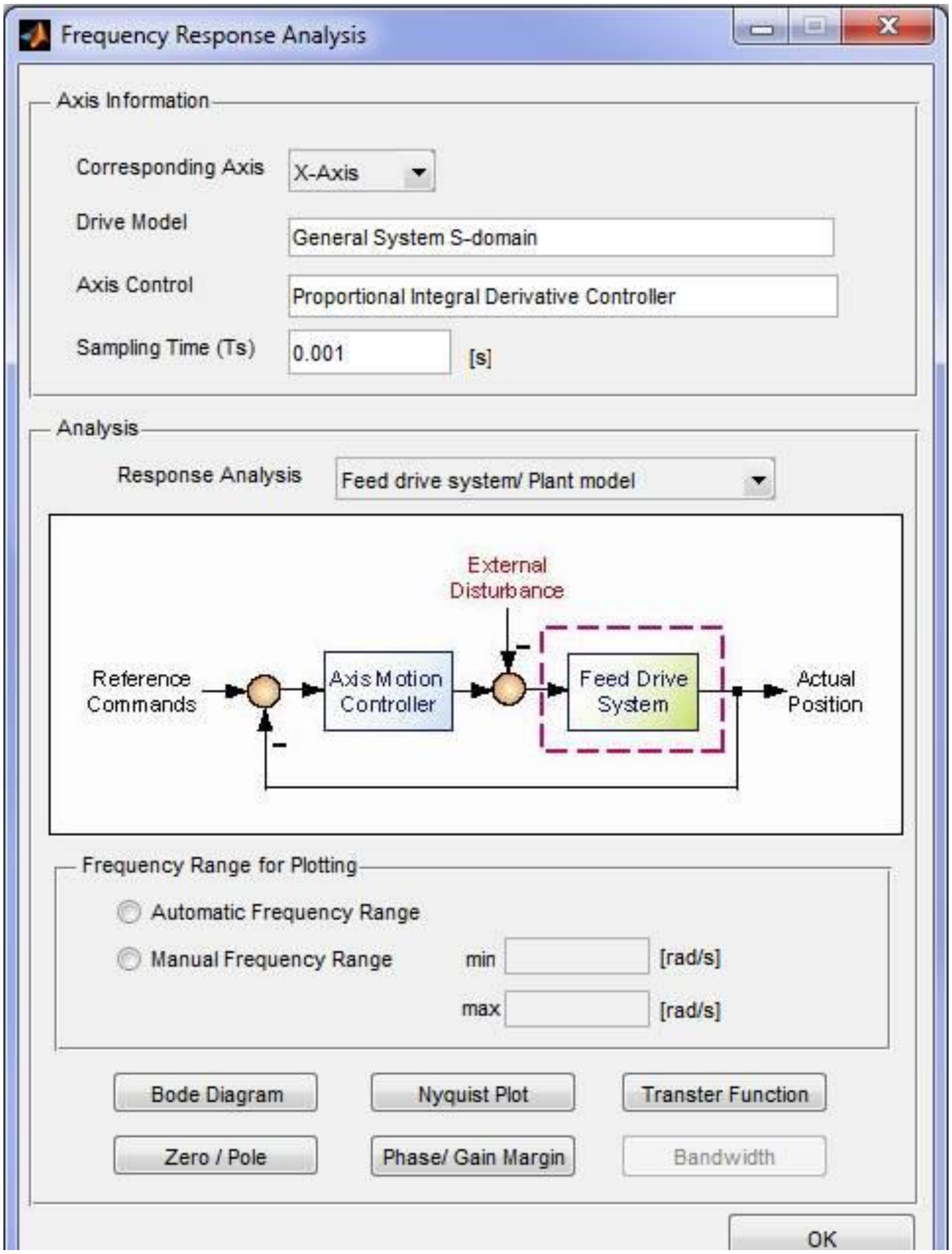
The advanced analysis function module is used to check the performance of the controller.

It includes three options: **Frequency Response Toolbox**, **Axis Tracking Toolbox** and **Contouring Toolbox**.



- **Frequency Response Toolbox**

In the frequency response analysis module you can check the results of Bode Diagram, Nyquist Plot, Phase and Gain Margin etc. of each axis.



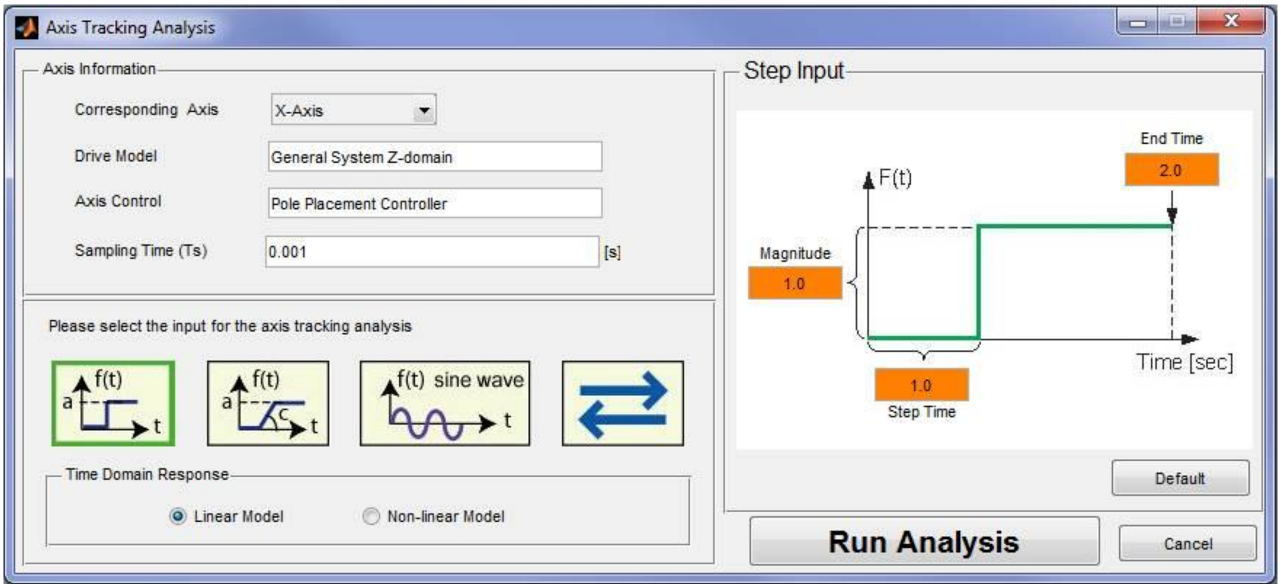
● Axis Tracking Toolbox

The Axis Tracking Analysis module analyzes the tracking performance for four types of inputs: **Step Input, Ramp Input, Sine Wave Input,** and **Back and Forth Input**.

In the right side of the interface, you can configure the input signal by defining the parameters.

You can choose a **Linear Model** or **Non-linear Model** as the type of the time domain response as well.

After configuration, by clicking **Run Analysis** button you can see the analysis result.



- **Contouring Toolbox**

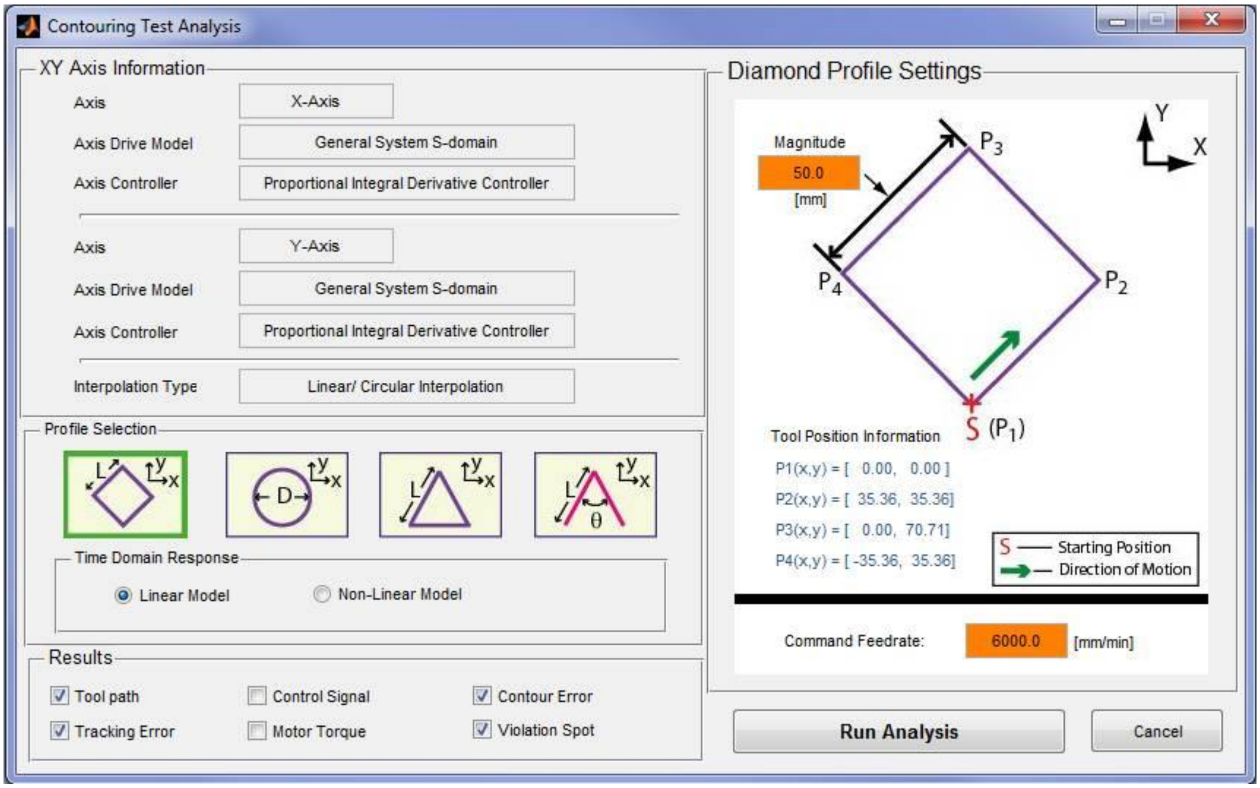
The Contouring analysis includes four types of profiles: **Diamond, Circle, Triangular** and **Cornered Angle**.

In the right side of the interface, you can configure the profile by defining the parameters.

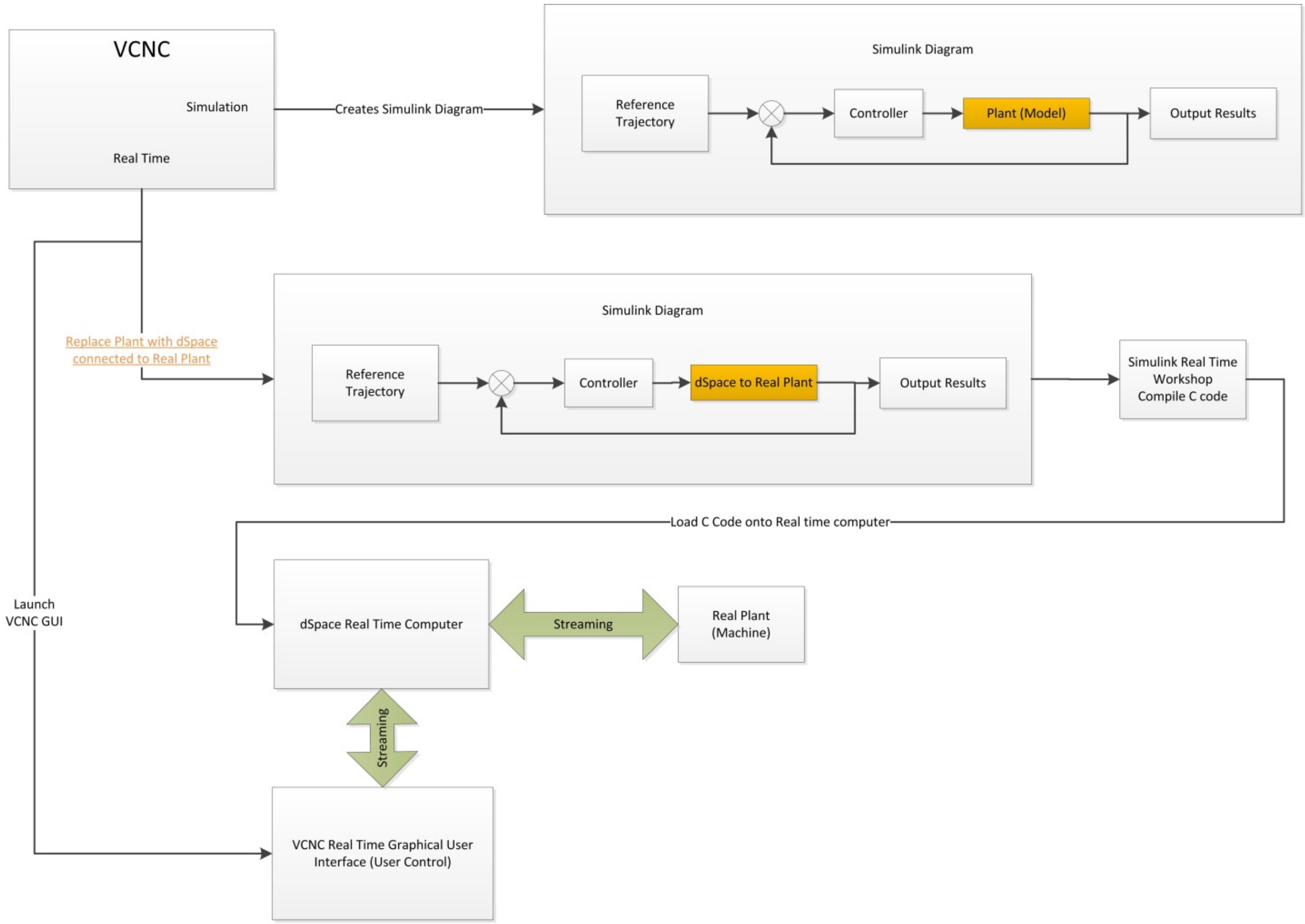
You can choose a **Linear Model** or **Non-linear Model** as the type of the time domain response as well.

Before running, you should check which results are expected and displayed.

After configuration, by clicking **Run Analysis** button you can check the analysis results based on the reference profile.



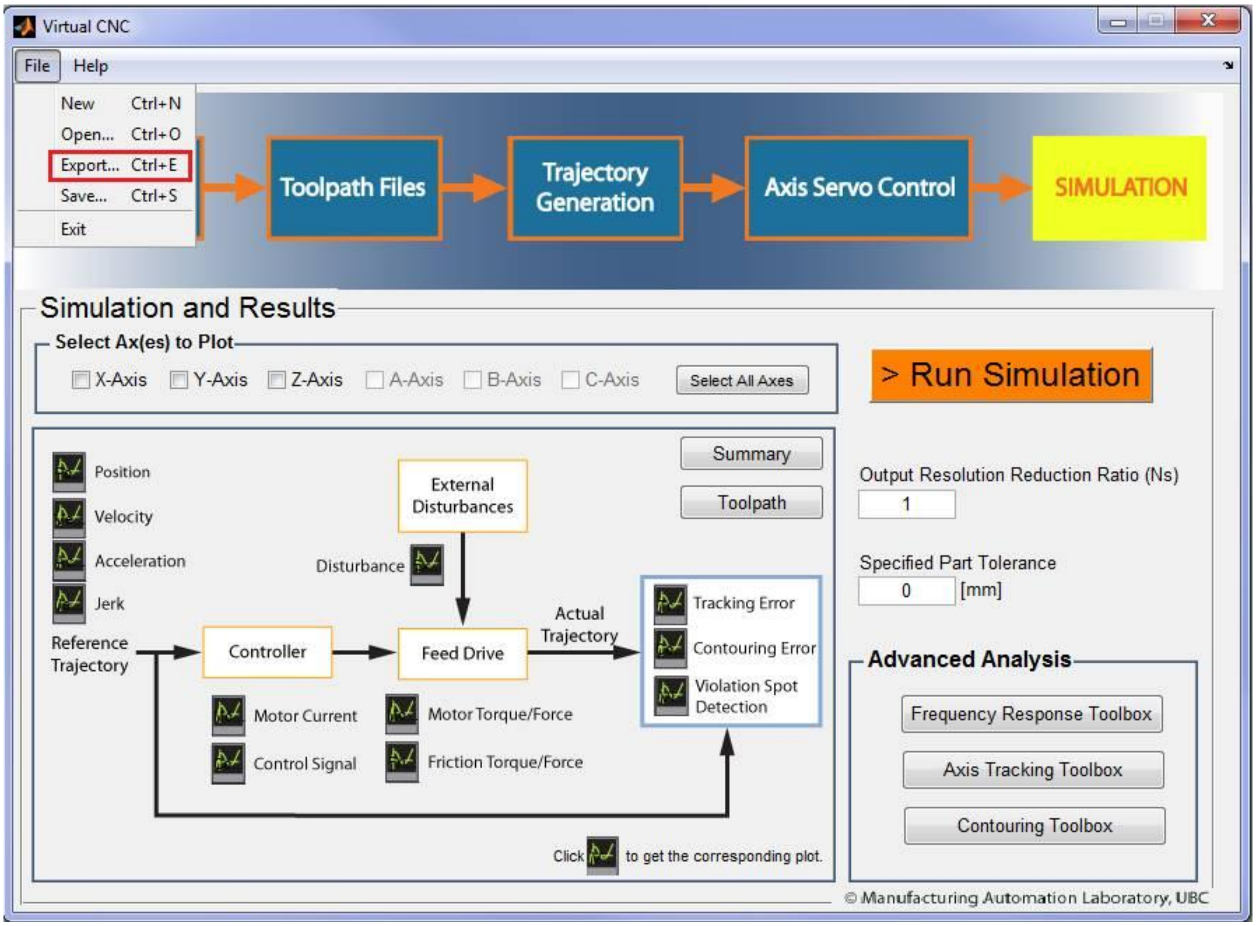
Overview of how VCNC Real Time works



1.7 Export Results

Export Results function under **File** menu can be used to export the useful simulated toolpath and error data by users.

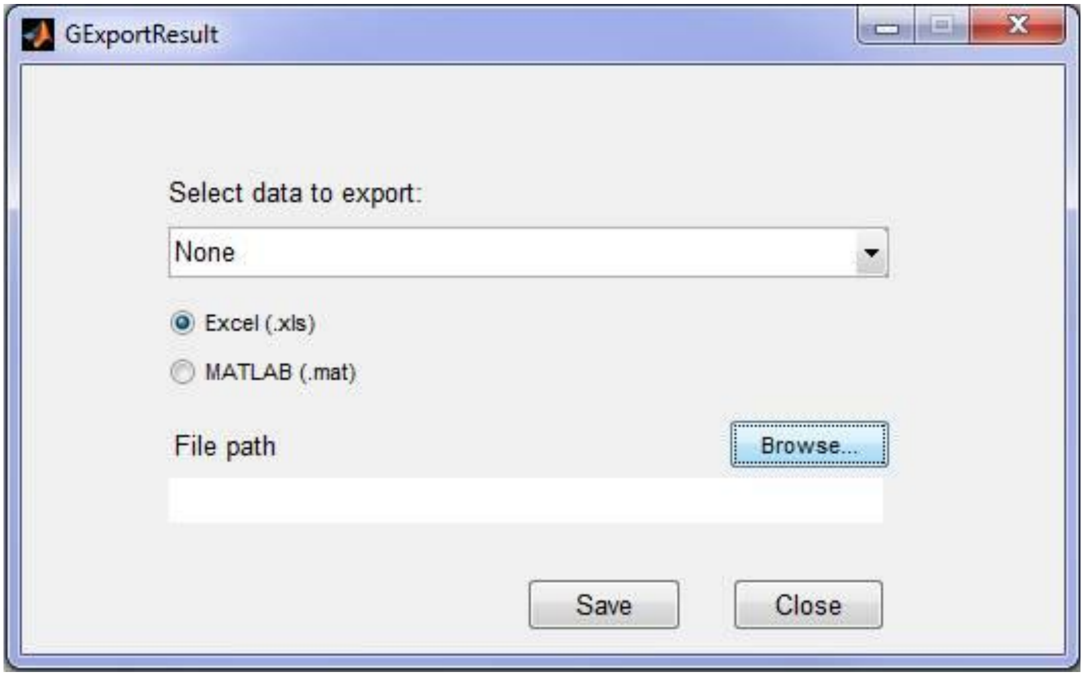
After simulation you can export the simulated results including the tracking error and contour error by clicking the **File** menu and selecting **Export** to open the interface of exporting results.

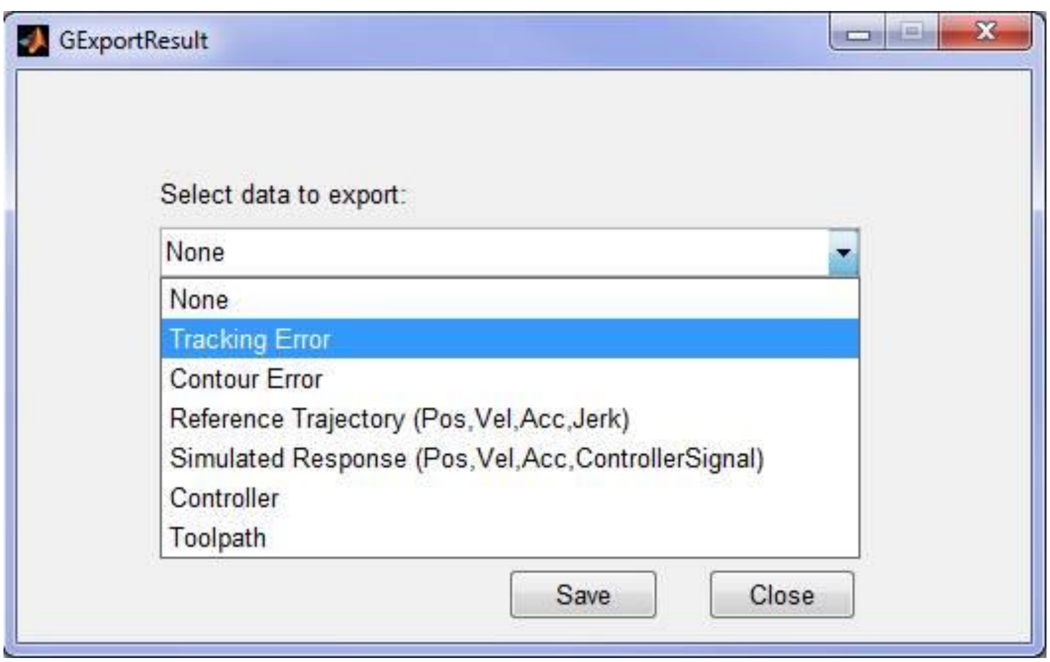


You can select different types of data to export by clicking the pop-up menu. Select the data first, which includes **Tracking Error, Contour Error, Reference Trajectory, Simulated Response, Controller** and **Toolpath**. The data file can be an Excel (.xls) file or MATLAB (.mat) file.

Then click the **Browse** button to choose a file path as the directory and enter the file name in the text box.

You can save the results to the directory you have defined before by clicking the **Save** button.





1.8 Support

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