Application Note

Input Shaping
Vibration Compensation with servo drives CMMT-AS and CMMT-ST

Brief description and practical example of setting and handling the Vibration Compensation with the servo drive controllers CMMT-AS and CMMT-ST using the Festo Automation Suite (FAS)

CMMT

100494

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Internet: http://www.festo.com

1. Software

Typ/Name	Version Software/Firmware	Partnumber
Automation Suite	>= V2.5.0.635	
CMMT-AS Plug-in	>= V2.5.1.2	
CMMT-ST Plug-in	>= V2.5.1.2	

Festo Automation Suite and Plug-In

1.1 Documentations

Typ/Name	Version/Date	Partnumber
Manual CMMT-AS-SW-EN		8195473
Manual CMMT-ST-SW-EN		8196476

Documentation Servo drive CMMT-AS

Documentation Servo drive CMMT-ST

2. Introduction

2.1 Mechanical axis systems and natural frequency

Mechanical axis systems are generally characterized by the fact that various components are caused to vibrate during a movement process. A timing belt e.g. represents such a component.
But other system components such as guides, bearings, spindles, gears, machine frames, moving masses/structures, etc. can also influence the vibration behavior and oscillate at one or more frequencies depending on their geometric and material properties . These natural frequencies are higher the lower the mass (and thus the damping) and the more unstable the system structure is.

2.2 Effects

When a mass accelerates or decelerates, the natural frequency of the system are stimulated. This can have different consequences for an automation task:

- Extended positioning time until the desired positioning window is reached or the vibrations have reached an acceptable level.
- The vibration causes additoanal loads in all moving parts (bearings, guides, spindles, toothed belts, clutches, gears, etc.). This usually leads to a reduction in lifespan.
- Increased of energy requirements.

2.3 Measures

The following measures may help avoid/reduce vibrations:

- Jerk: changing the jerk can partially reduce the vibrations. However, this value is often limited for mechanical or drive-specific reasons, which leads to an extension of the positioning time.
- Notch filter: it is used when certain frequencies (usually above 200 Hz) have a disruptive effect on the drive behavior and cannot be suppressed by the control loop.
- As a further measure, our drive controllers offer the possibility of reducing the vibration behavior through control technology. This function is called I**nput Shaping**.

3. What is “Input Shaping”?

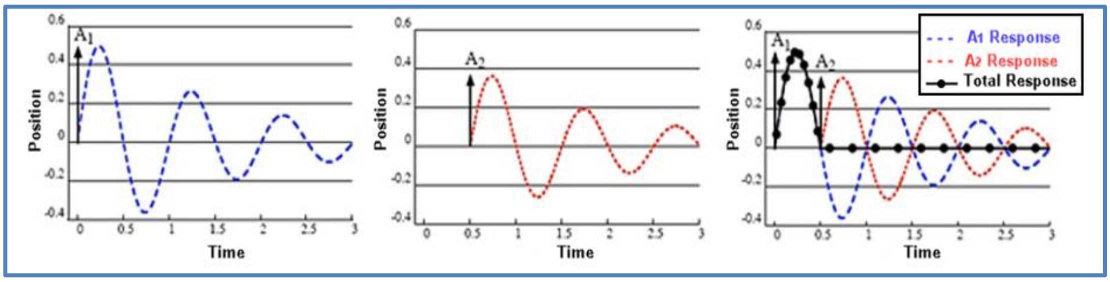
The **Input Shaping** (“Vibration Compensation” in the **Festo Automation Suite**) is a control strategy for compensating of natural frequencies in mechanical systems.

3.1 How does Input Shaping work?

With the help of **Input Shaping**, any time-dependent control signal (e.g. position-, speed-, acceleration-. Deceleration- or force-signal) can be modified in a way that the excited natural oscillations of the system compensate each other through superposition.

The basic idea of **Input Shaping** is to superimpose the already excited natural oscillation of the system by exciting a second oscillation in such a way that both oscillations cancel each other out in the overall response of the system. The decisive factor here is the design of the second pulse excitation with regard to the timing and amplitude.

The amplitudes and time locations of the pulses are obtained from the natural frequencies and damping conditions of the system.

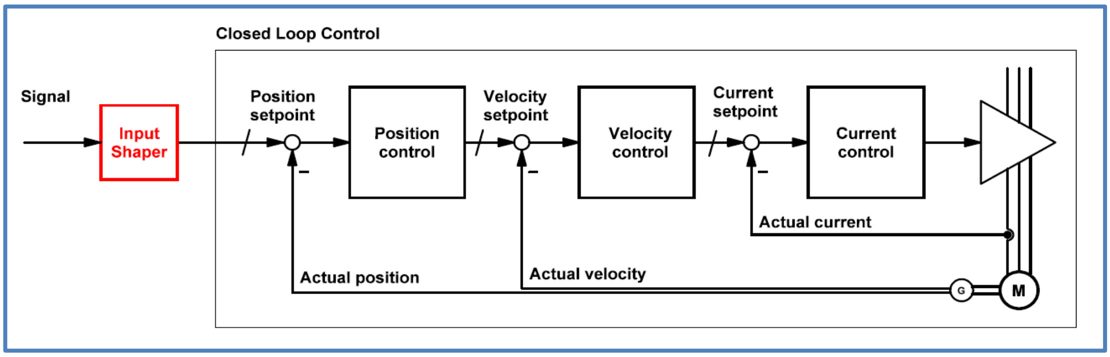


Attention: modifying the control signal results in a longer positioning time!

This can possibly be compensated by higher values for acceleration and/or jerk, but in any case must be determined experimentally.

The **Input Shaper** is outside of the control loop and therefore has no influence on the stability of the closed-loop system. This function is therefore also suitable for open-loop controlled (stepper) motors.

The shape of the signal can be realized very robustly against errors in the system parameters (approx. +- 15% deviation of the natural frequency can still eliminate ›90% of the vibrations).



In order to achieve the desired results, the natural frequency of the system must be communicated to the **Input Shaper**.

Notice:

In multi-axis systems, different natural frequencies of the axes often occur, some of which overlap. Here, compensation of the main exciting axis is often sufficient to sufficiently stabilize the system.

Demarcation:

- With the CMMT-AS/ST-... controllers, **Input Shaping** **only** works in the operating mode “Positioning mode”.
- Notch filter (blocking filter): this filter function works **inside** the control loop and therefore has a strong influence on the design of the control and the stability of the control.
  A notch filter should e.g. be used if a certain speed causes the drive system to produce high-frequency oscillations in the control signal, which cannot be suppressed by the speed control.
- Auto-Tuning: parameters for position and speed controllers can be determined. To do this, the current controller must already be designed, suitable start parameters for position and speed controllers and the amplitude of the excitation signal must be present. The start parameters for position and speed controllers are automatically determined based on the drive configuration. An adjustable number of measurements provides the desired parameters. Detecting faults is **not** possible with auto-tuning.

4. Determination of the natural frequency

In order for **Input Shaping** to be useful, the natural frequency of the system must be known. There are various ways to determine this resonance frequency (usually in a range of › 2 Hz and ‹= 10 Hz) of a mechanical system. The following examples are mentioned:

4.1 Recording the motor current with the Festo Automation Suite

Using the integrated trace function, the **Festo Automation Suite** software tool can record the actual current of the motor. See Chapter 6.

4.2 Recording with an external measuring system

For this purpose, a suitable measuring system is coupled directly to the moving mechanics. However, this requires increased mechanical and electrical installation work.

4.3 Accelerometer

This method uses a sensor that can detect accelerations. Qualified preparation of the data can provide conclusions about the resonance behavior of a mechanism.

4.4 Measurement with an acoustic measuring device

Special devices determine the frequency spectrum using a microphone and sophisticated evaluation electronics. However, occasional use is accompanied by high acquisition costs. In addition: audible frequencies are generally not in the critical spectrum due to small amplitudes and high attenuation.

4.5 Using a Smartphone App

There are various applications for the different smartphone operating systems. These so-called frequency spectrum analyzers carry out vibration measurements and can deliver quite satisfactory results.

4.6 Transfer of the product parameters from the HGO

If a mechanical axis system is designed using the Festo design software **HGO** (Handling Guide Online), an expected resonance frequency is calculated from the known database values of the individual components. This can be transferred with the complete parameter set to the **Festo Automation Suite** to commission the system:

Attention: the "EDGE" browser (Microsoft) has the pop-up blocker activated by default.
Deactivate first, then the file can be saved in the download directory.

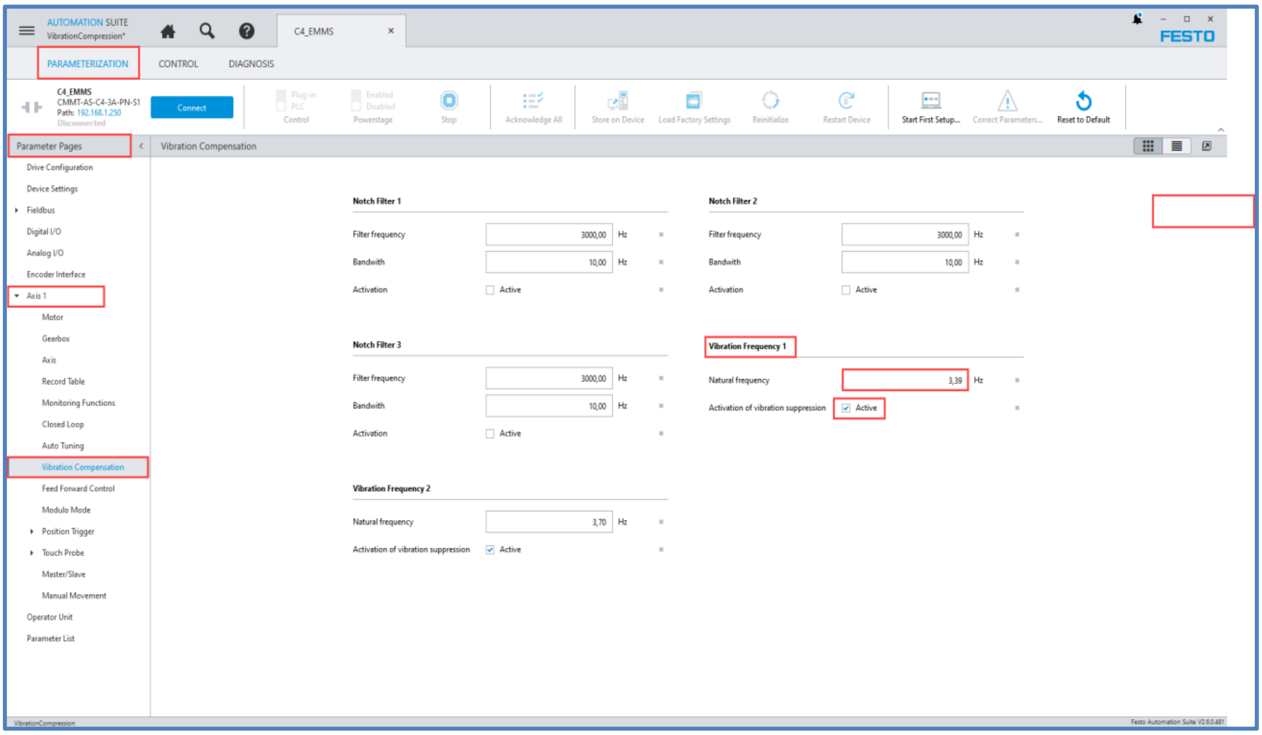
4.7 Manuel setup

Experience has shown that the resonance frequencies, that occur in mechanical systems, are within a few Hertz (> 2 Hz and <= 10 Hz) in the very low frequency range. By trying out several values, you can quickly find out how to use the determine parameters for satisfactory **Input Shaping**.

5. Settings for the Festo Automation Suite

To activate **Input Shaping**, the following measures are necessary:

- Select the desired axis under “PARAMETERIZATION/Parameter pages”.
- Select the “Vibration compensation” entry
- Enter values for “Vibration frequency 1” and/or “Vibration frequency 2”
- Activate the respective vibration suppression



6. Practical example

An experimental setup is intended to show how and with what effort the natural frequency of an axis mechanics can be determined using the **Festo Automation Suite**. Here are the components and application parameters used:

Hardware:

CMMT-AS-C4-3A-PN-S1

EMMS-AS-70-M-LS-RM

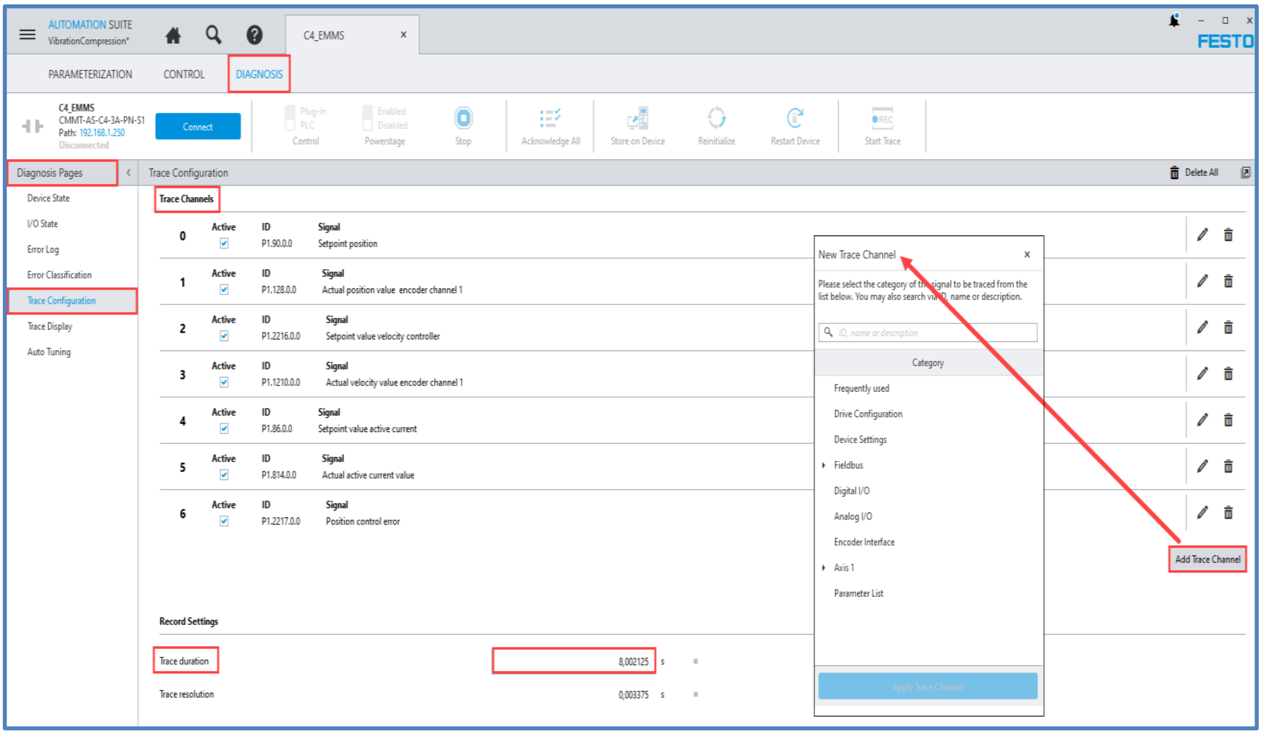
EGC-80-960-TB-KF-0H-GK

Application data:

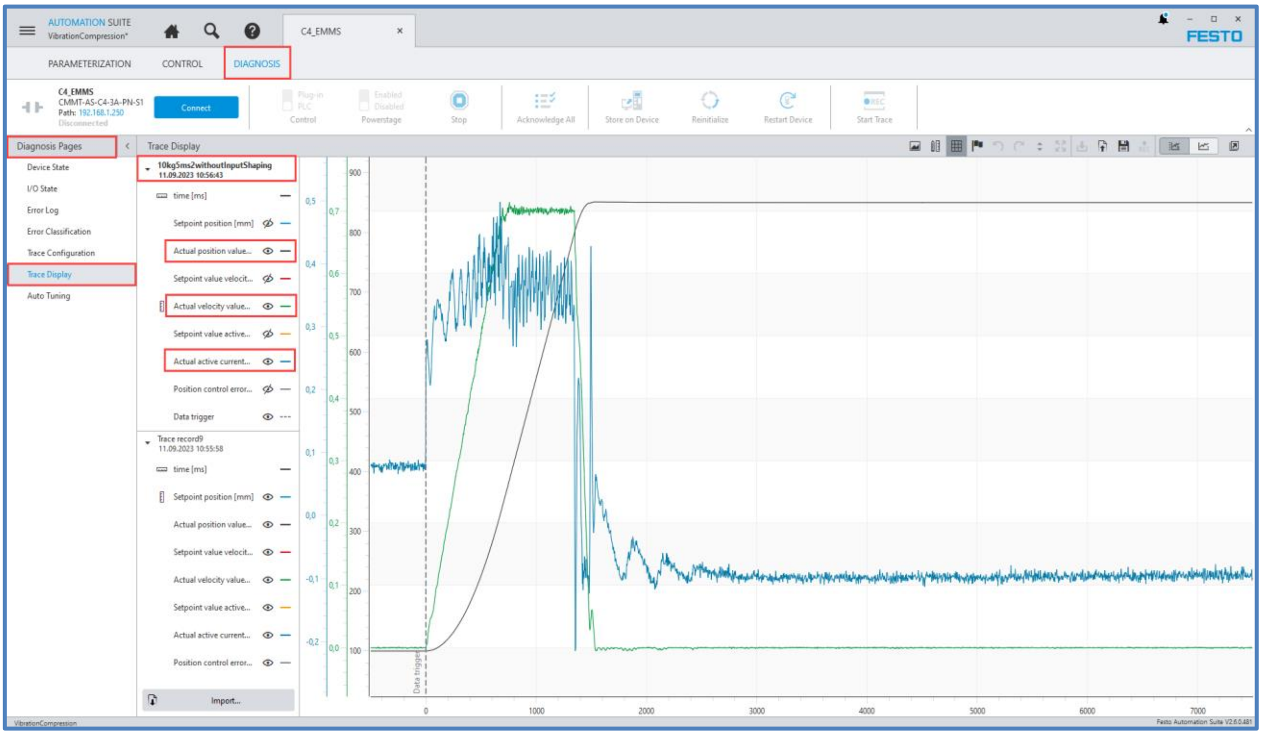
Moving mass	10 kg
Velocity	0,7 m/s
Acceleration	1 m/s²
Deceleration	5 m/s²
Jerk	500 m/s³

Trace configuration:

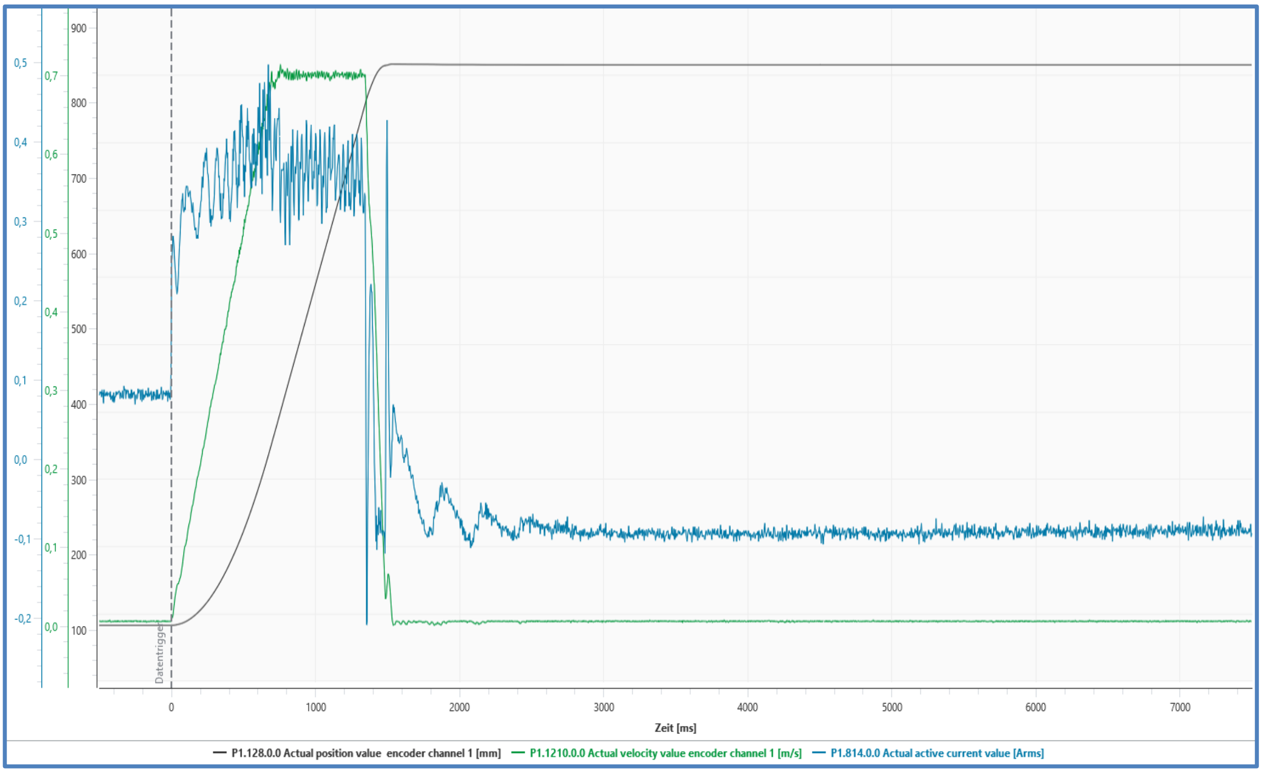
Various recording channels as well as a desired recording duration can be parameterized at "DIAGNOSIS/Trace Configuration".



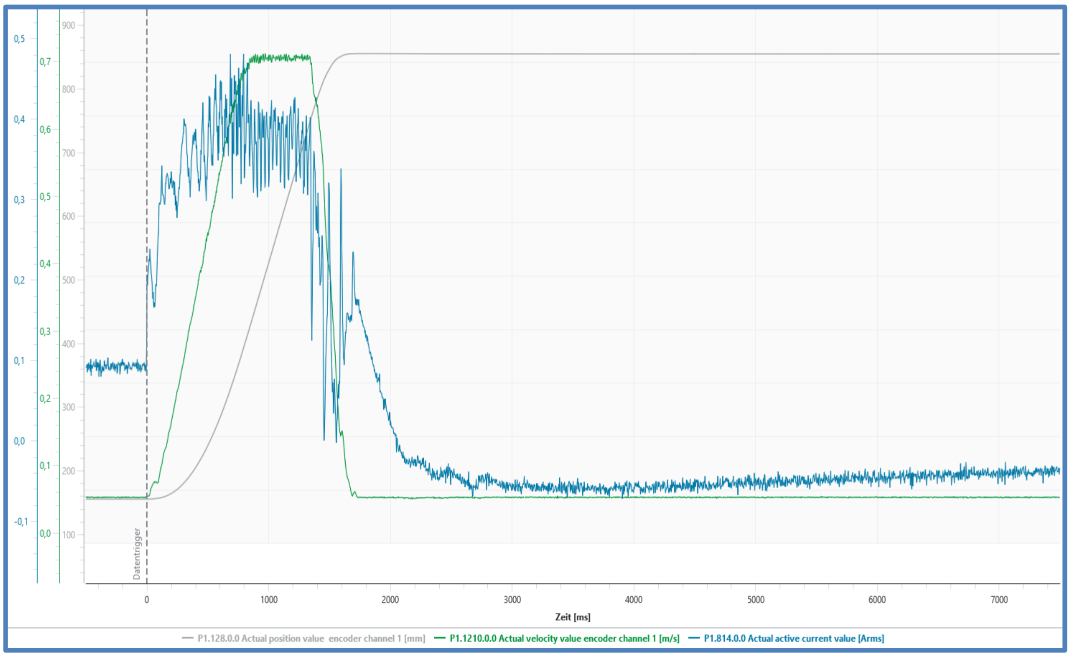
After selecting a specific trace, the "DIAGNOSIS/Trace Display" page offers the desired recording channels for viewing.



Trace without Input Shaping

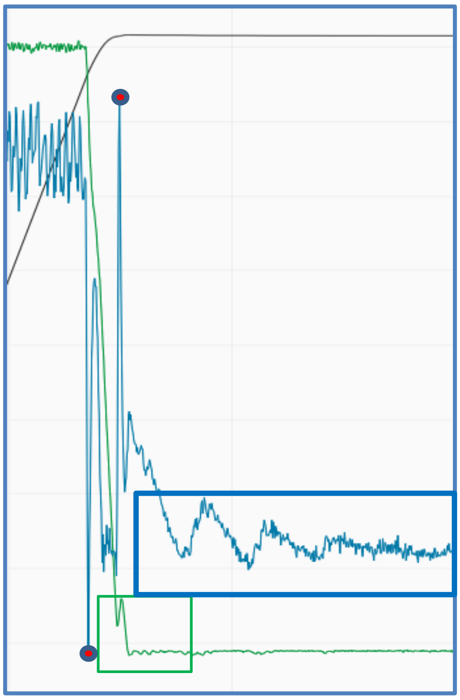


Trace with Input Shaping

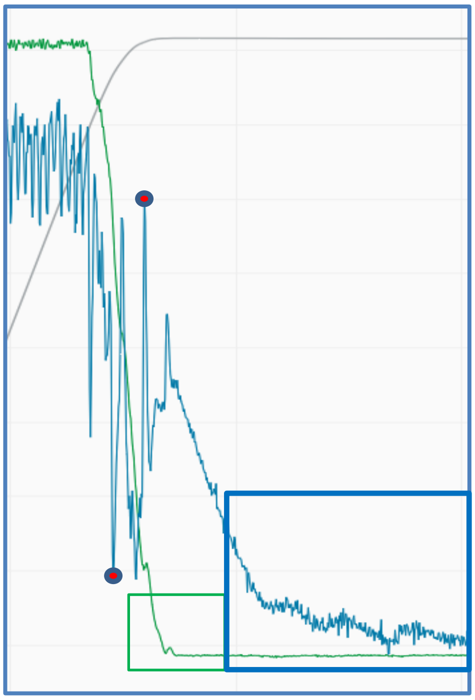


Please note that acceleration ($1 m/s^2$) and deceleration ($5 m/s^2$) strongly influence this graphic.

Without **Input Shaping**



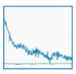
With **Input Shaping**



The comparison without/with **Input Shaping** becomes clear when enlarged. With **Input Shaping**:

 The current peaks are significantly lower

 The speed curve is much smoother (more balanced)

 The current signal has less peaks and the current value is lower

The natural frequency was determined from the trace <u>without</u> Input Shaping:

Measure the first peak:

Measure the next peak, here peak 4:

Calculation of the natural frequency:

$$\left(\frac{\mathbf{1}}{\left(\frac{\boldsymbol{Timemax - Timemin}}{\boldsymbol{Numberpeaks}}\right)}\right) * \mathbf{1000}$$

For this example:

$$\left(\frac{1}{\left(\frac{2423.25 - 1539.00}{3}\right)}\right) * 1000 \qquad = \mathbf{3.39\ Hz}$$

Enter the value of **3.39** Hz in the **Festo Automation Suite**. Small corrections upwards or downwards can still bring about some improvements.

7. Videos about „Input Shaping“

Input Shaping.mp4

Without_With Input Shaping.mp4

8. Links

Festo Automation Suite + Plug-in DE

Festo Automation Suite + plug-in EN

Dokumentation CMMT-AS DE

Documentation CMMT-AS EN

Dokumentation CMMT-ST DE

Documentation CMMT-ST EN