Resonance

General dive in to resonance, and common issues

Thanks to Frix_X, AndrewMcGr, EddietheEngineer, 3D_printers and a whiteboard, and Pnewb.

Presented at:

Voron Reno Vice

October 5-6, 2024

Reno, NV

Who am I

- My secret agent name is Reth.
  - The name was chosen because this is my D&D character name.
  - Currently up to Reth XV
- Currently hold a BSEET, MSEE, and JD.
- Work as a Primary Patent Examiner at the United States Patent and Trademark office, where I examine semiconductors.
- I am not a mechanical engineer. Basically, I am learning as I go.

CYA notice and disclaimer:

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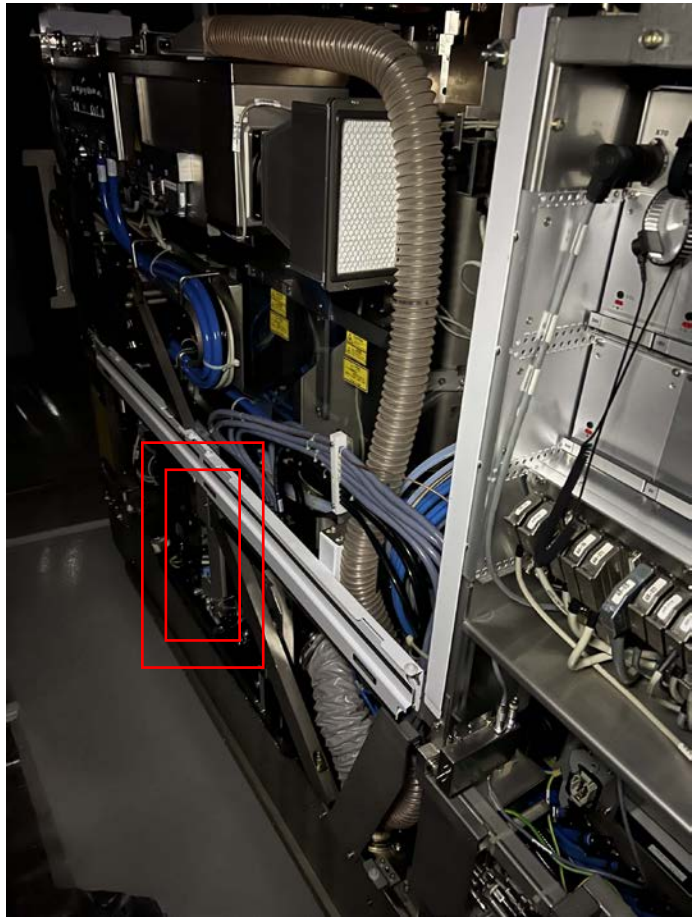
Previous exposure to resonance

- Worked as a field service engineer with ASML.

This was worse than the umbilical

This thing has one cam style screw and one locking screw. It took forever to adjust. Days could be spent adjusting it. With each resonance test taking about 30-45 minutes



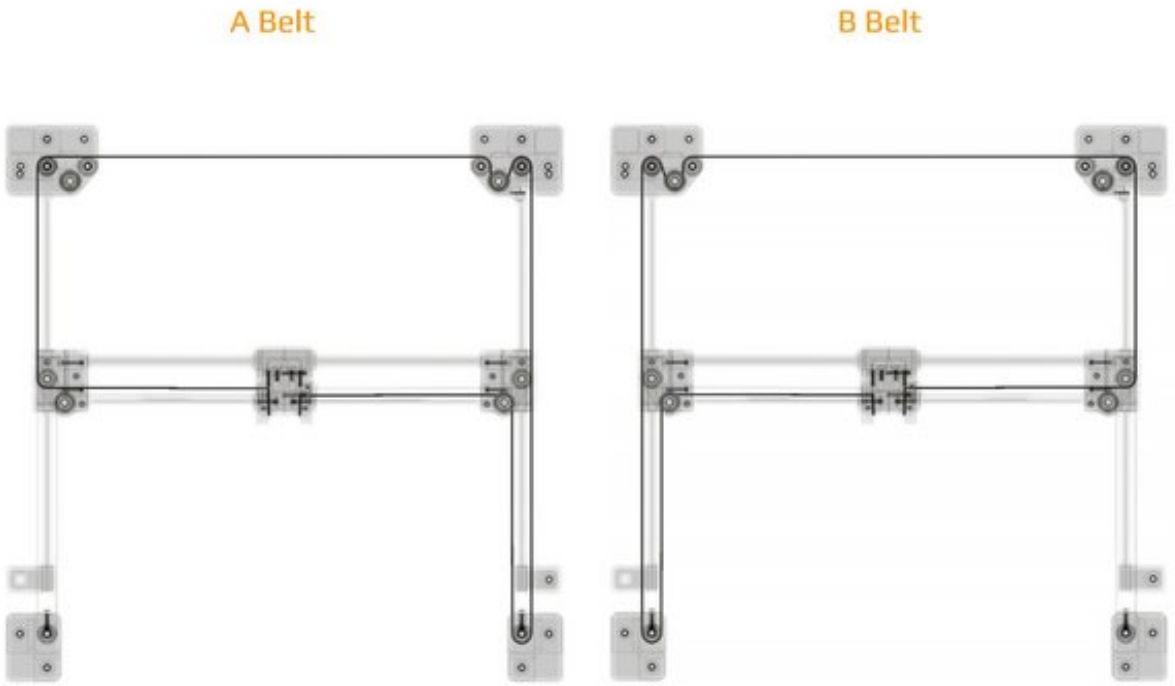
Simpler system: but more frustrating

It is more frustrating because Voron has not spent hundreds of millions of dollars characterizing all the resonance in the machine such that one could identify each individual aspect's resonance frequency.

In addition, our tool are not build on an assembly line, and are parts are not high precision. Therefore, each printer is a unique printer.

Thankfully the big parts seem to react the same in resonance

Other gantry systems do not necessarily have the same resonance profiles as Vorons

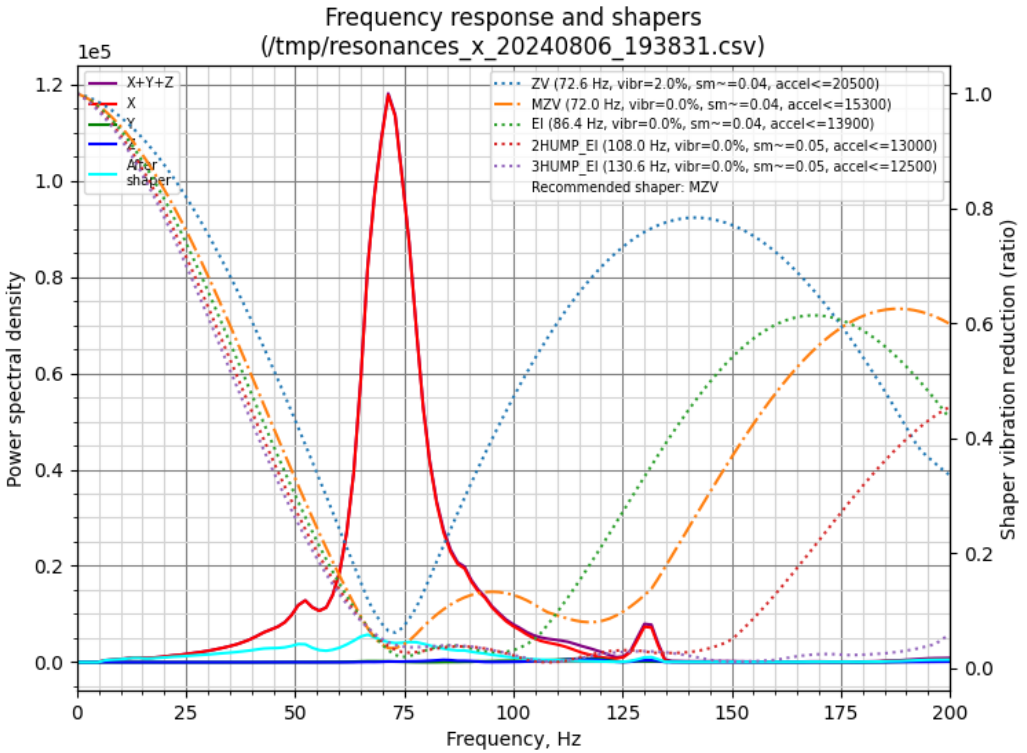


What is resonance

The natural frequency at which an object exacerbates oscillations based upon an external vibration.

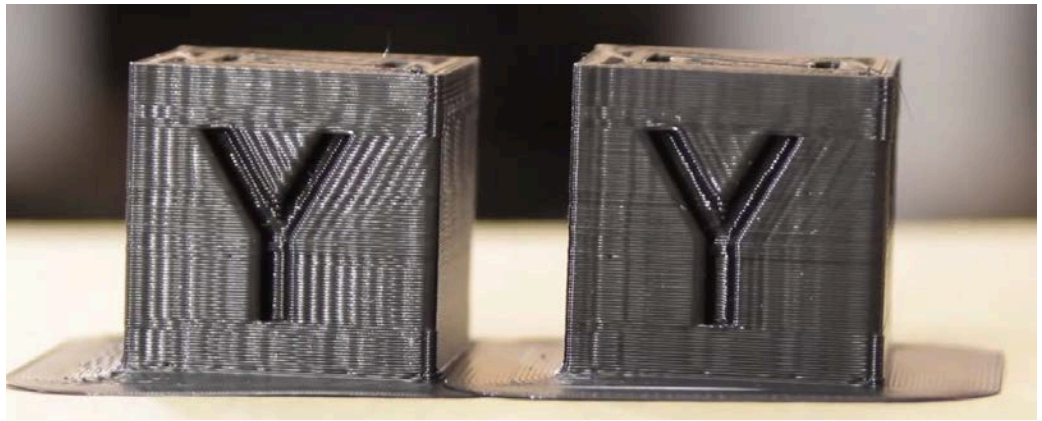
Damping ratio is the loss of energy of the oscillating system by natural dissipation. The decay of the oscillations in a system after excitation

In Voron printers our damping ratio is normally in the range of 0.04-0.06
Standard Klipper sets the value to 0.1



Why do we need to worry about resonance; Why didn't we worry about it before

- Printers are getting faster.
- Ghosting/ringing/resonance is more pronounced with increased acceleration
- The faster you go the harder it is to turn



	MK3	Voron VT/V2 (PLA)
Internal perimeter	60	120
External Perimeter	35	120
Internal accel	800	3000
External accel	800	3500

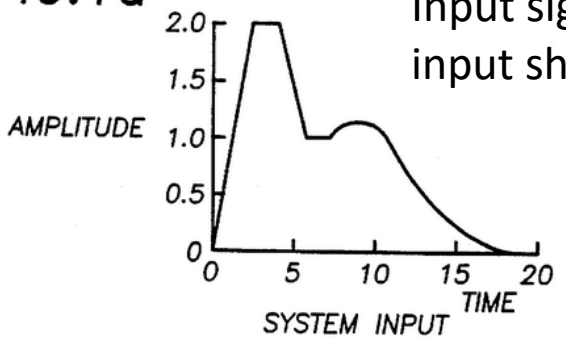
*ABS can be run faster

What affects input shaper measurements

- Belt tension and belt alignment
- Weight
  - Toolhead
  - X-axis
- Center of Mass (COM) and Center of Gravity (COG) of toolhead
- Hotend fan, part cooling fan, and if really strong electronics bay fan
- Position of ADXL
- Wire connecting ADXL to Pi
- Umbilical
- Loose screws
- Print quality of motion parts (xy joints)
- Material of motion parts (plastic vs. metal)
- How well the printer was built
- Anything that affects or has an effect upon the gantry (motion system)

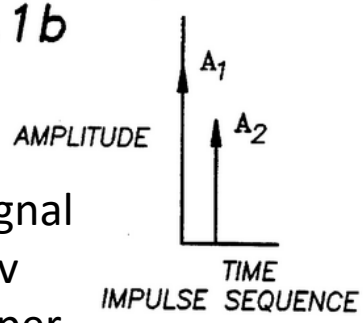
What is input shaper doing?

FIG. 1a



Input signal without input shaper

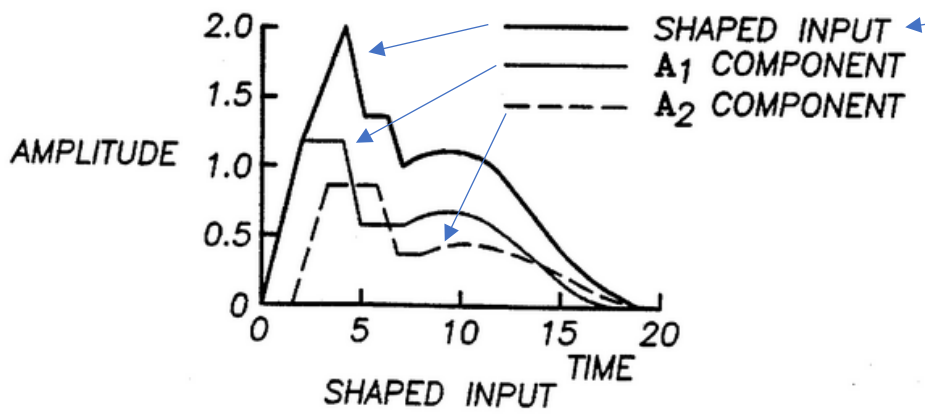
FIG. 1b



Shaper signal
This is a zv input shaper signal

- Input shaper is a feedforward motion correction in an open loop mode.
  - We measure the resonance and then choose an shaper (filter) to cancel the main reasonance.
- Input shaper applies one or more input pulses of a precalculated amplitude at a precalculated time to adjust the input to the TMC drivers.
- This will adjust the input signal to correct for acceleration related vibrations.

FIG. 1c



This is the resulting input signal with input shaper

What values are important to input shaping

- The two values which are important to input shaping are Freq and Damping ratio of the printer
  - These are physical characteristics of the machine that are measured by the ADXL
  - Klipper takes these values, along with a SCV, and Max Smoothing allowed to generate vibr% (remaining vibrations)
- Klipper uses Freq and Damping ratio to generates the A & T values for each shaper which will be applied to the input signal to the TMC drivers and the TMC drivers will control motors

```
def get_mzv_shaper():
    df = math.sqrt(1. - SHAPER_DAMPING_RATIO**2)
    K = math.exp(-.75 * SHAPER_DAMPING_RATIO * math.pi / df)
    t_d = 1. / (SHAPER_FREQ * df)

    a1 = 1. - 1. / math.sqrt(2.)
    a2 = (math.sqrt(2.) - 1.) * K
    a3 = a1 * K * K

    A = [a1, a2, a3]
    T = [0., .375*t_d, .75*t_d]
    return (A, T, "MZV")
```

```
def get_ei_shaper():
    v_tol = 0.05 # vibration tolerance
    df = math.sqrt(1. - SHAPER_DAMPING_RATIO**2)
    K = math.exp(-SHAPER_DAMPING_RATIO * math.pi / df)
    t_d = 1. / (SHAPER_FREQ * df)

    a1 = .25 * (1. + v_tol)
    a2 = .5 * (1. - v_tol) * K
    a3 = a1 * K * K

    A = [a1, a2, a3]
    T = [0., .5*t_d, t_d]
    return (A, T, "EI")
```

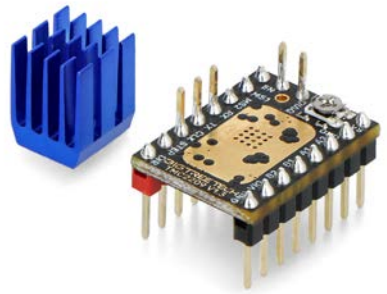
What is Klipper doing

- Klipper is applying the A and T values to each movement.
- It can do this because it knows each movement before hand by means of our gcode.
- There should be no surprises

Side discussion:
Input shaper vs TMC autotune

- Input shaper adjust the signal to the TMC Drivers to cancel out acceleration related vibrations.
  - Change of the toolhead path
- TMC autotune adjust the TMC drivers to cancel out mainly speed related vibrations.
  - Change of the internal motion control, internal current loops, etc.
- Input shaper and TMC_Autotune are complementary to each other

Side discussion:
What are TMC drivers doing



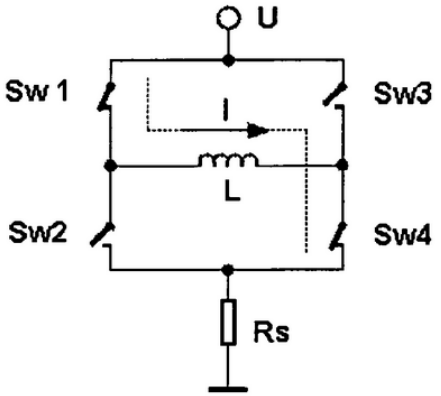


FIG. 1(A)

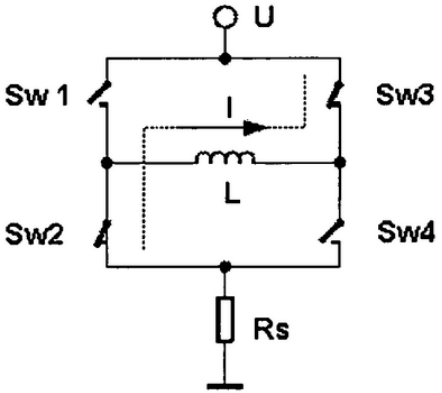


FIG. 1(B)

On Phase

Fast Decay

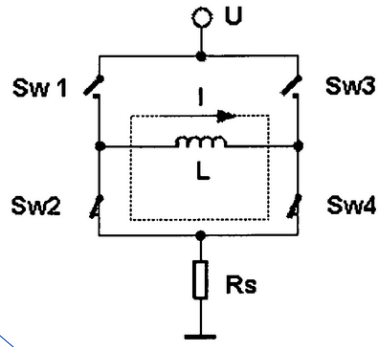
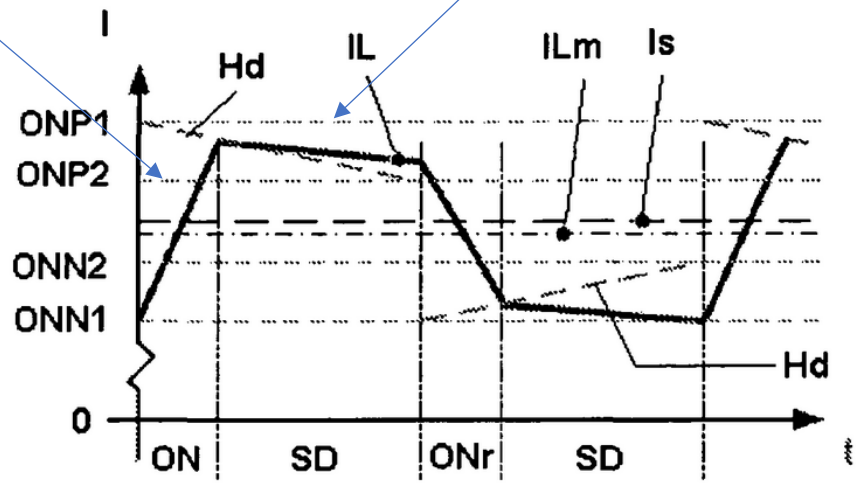


FIG. 1(C)

Slow Decay



Reverse On Phase,
Similar to Fast Decay with more control

FIG. 5

How to Read Input Shaper and Belts Graphs:

Belt Shaper, or Compare Belts

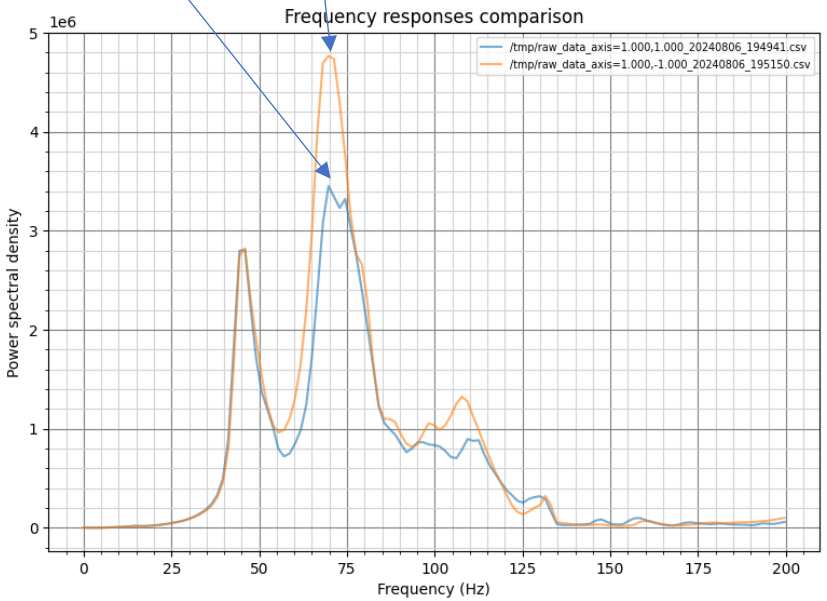
standard Klipper vs. Shaketune

for standard Klipper see “Measuring Resonances” under “Testing custom axes”

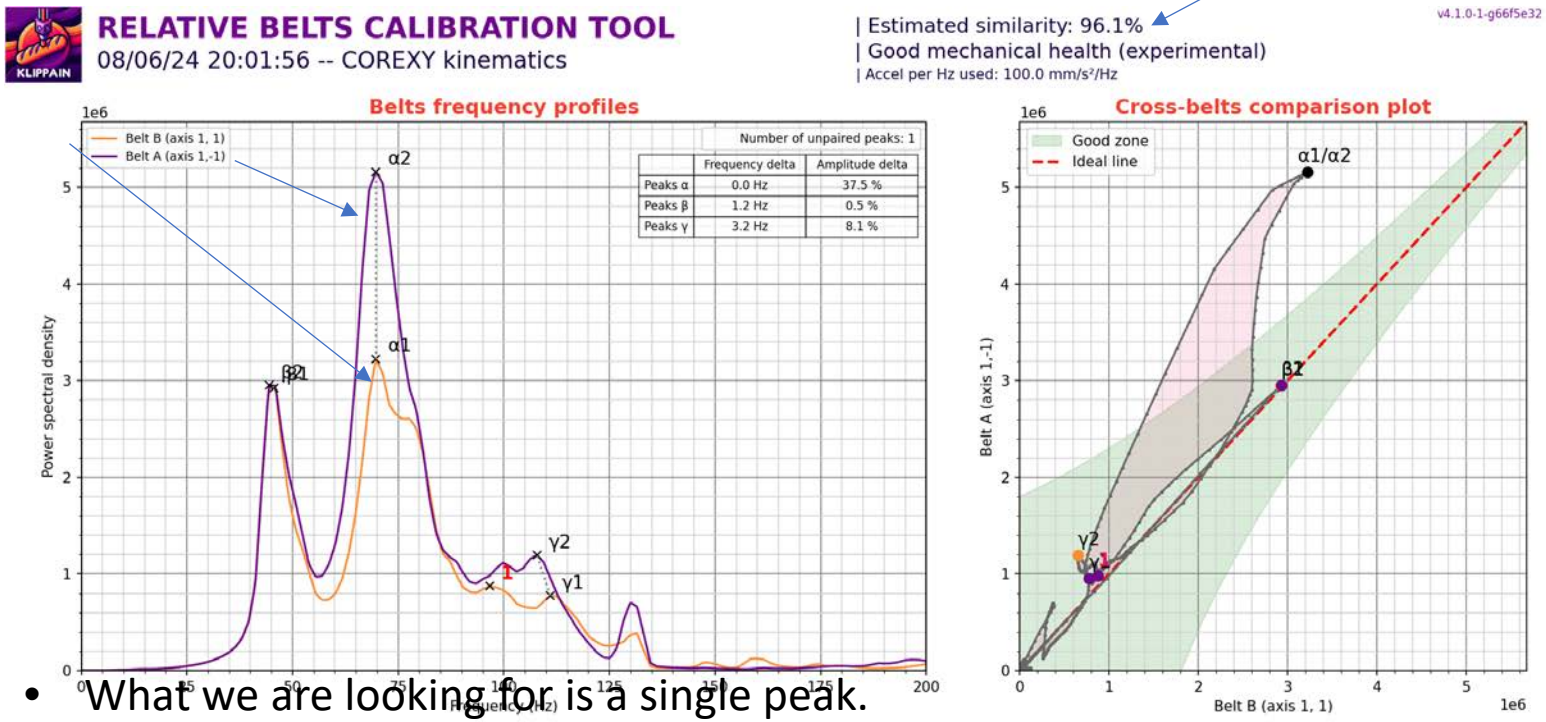
DO NOT RELY **ONLY** ON THIS VALUE

A-belt = (1,-1)

B-belt = (1,1)



- Belt shaper just tells us relative belt tension.
- It does not tell us absolute belt tension.



- What we are looking for is a single peak.
- What we will settle for is a double peak.
- These are double peaks with crap, but they are good enough.
- Belt shaper cannot be used by itself as a troubleshooting device. It must be paired with input shaper.
- Choose Freq over amplitude if you need to make the choice.
- Frix would like me to inform you all that both are important, and to make the highest peaks as close as possible

Belts: Closer Look

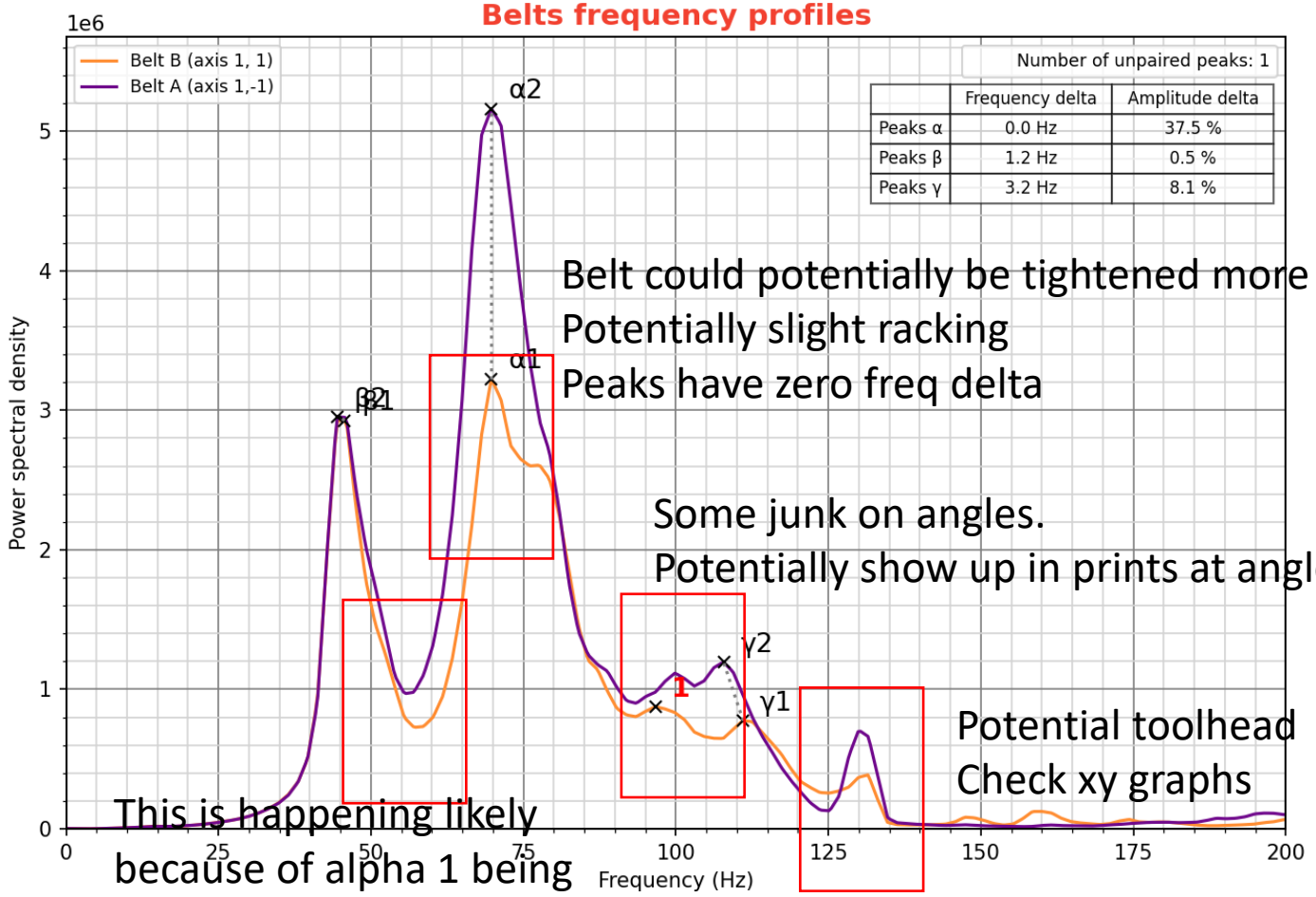
Do not rely **only** on this.
Shape of the graphs more important

RELATIVE BELTS CALIBRATION TOOL
08/06/24 20:01:56 -- COREXY kinematics

v4.1.0-1-g66f5e32

| Estimated similarity: 96.1%
| Good mechanical health (experimental)
| Accel per Hz used: 100.0 mm/s²/Hz

Belts frequency profiles



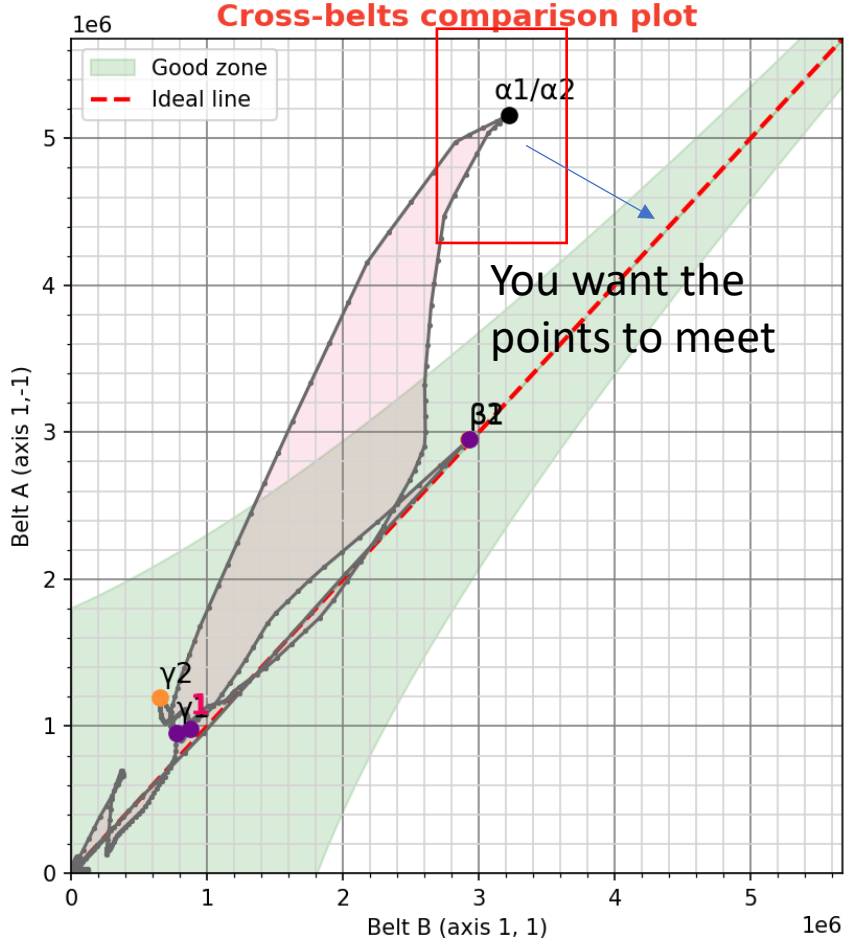
Belt could potentially be tightened more
Potentially slight racking
Peaks have zero freq delta

Some junk on angles.
Potentially show up in prints at angles

Potential toolhead
Check xy graphs

This is happening likely because of alpha 1 being low.
Not an issue in and of itself

Cross-belts comparison plot

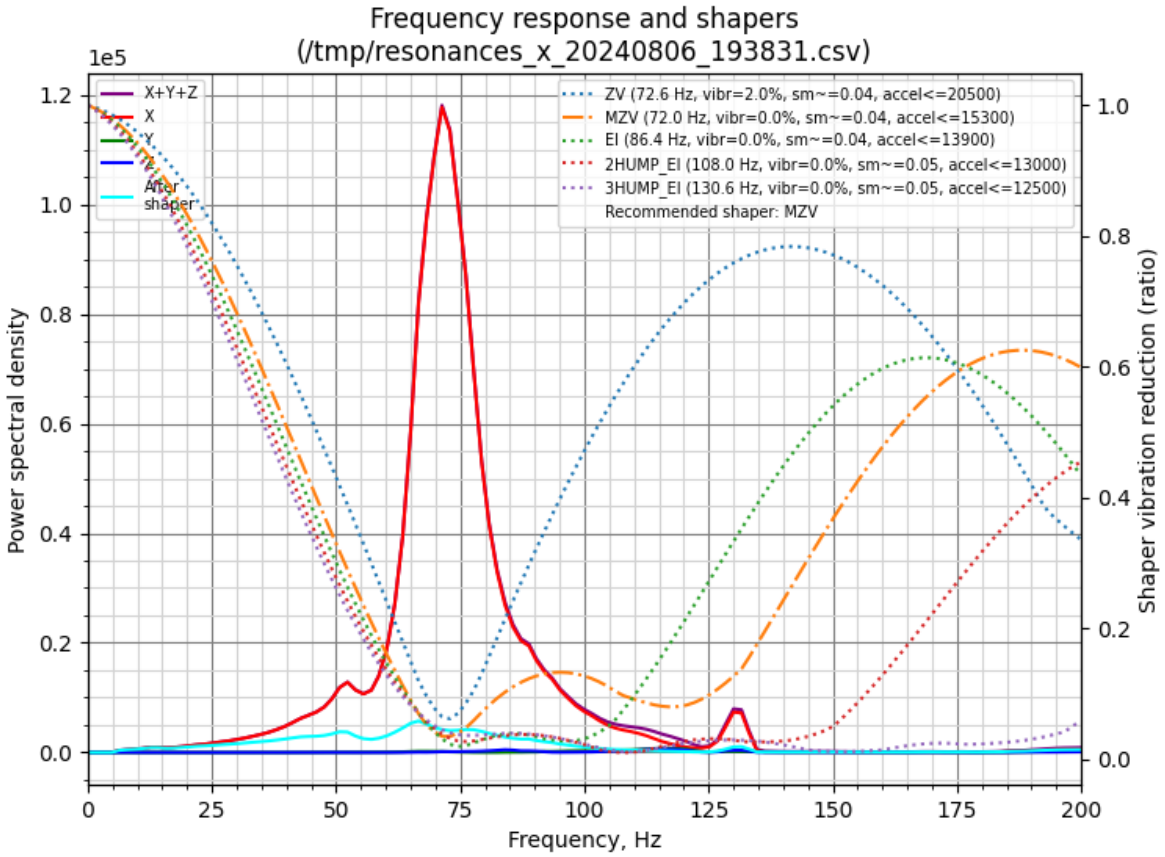


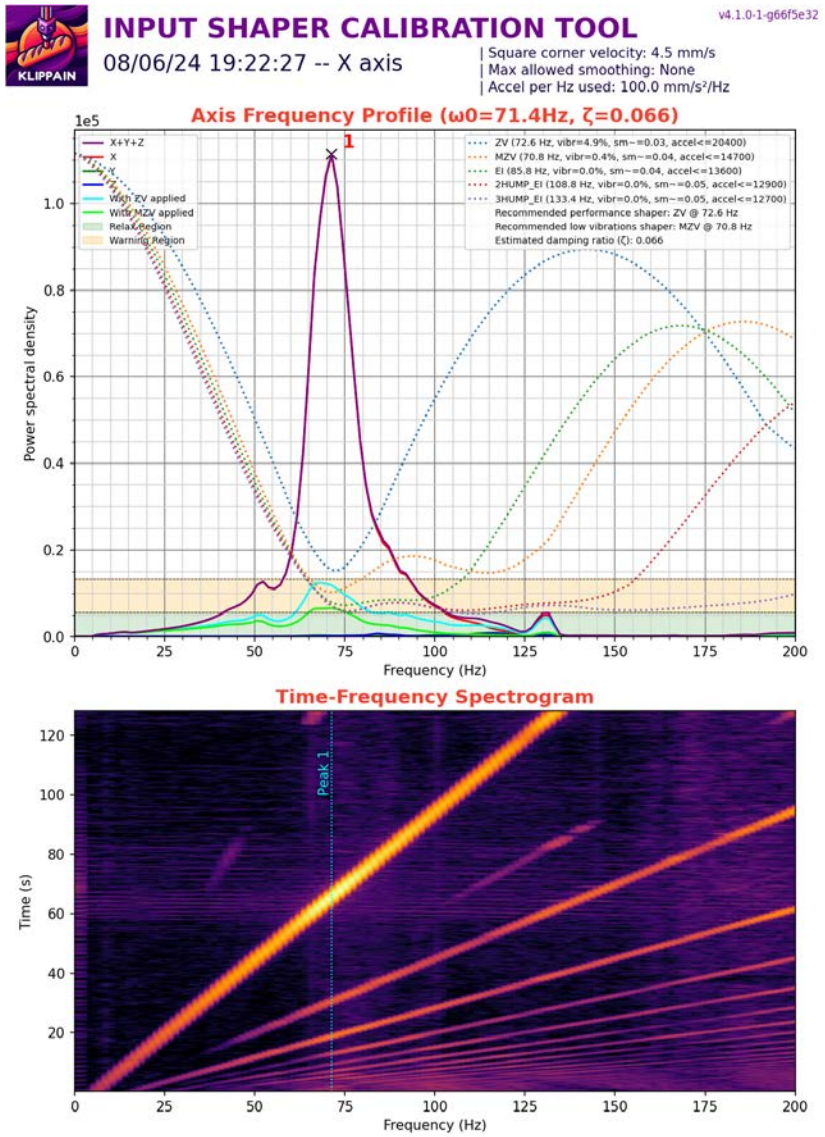
You want the points to meet

Higher freq have less impact on the prints.

X-Input Shaper

standard Klipper vs. Shaketune





Biggest difference is Damping ratio

Klipper defaults to 0.1, Shaketune calculates it from the graph

Then this damping ratio is used for shaper calculations.

X-input shaper: Closer Look

Informational only: signals inherent freq and damping ratio

Shaketune allows for SCV as a variable
This value will contribute to max accel, smoothing, and vibrations

Shaketune allows for max smoothing as a variable. This will directly influence max accel and vibrations. Default to value set in printer.cfg

Accel_per_hz: a Klipper variable which determines how much energy you are putting into the system per each pulse. 75 HZ is default. I like 100hz. 125hz can be to much. Higher accel_per_hz will cut down on noise. However, it can also remove/mask issues.

The shape of the Shapers that can be applied

Combined signal
This is what klipper uses

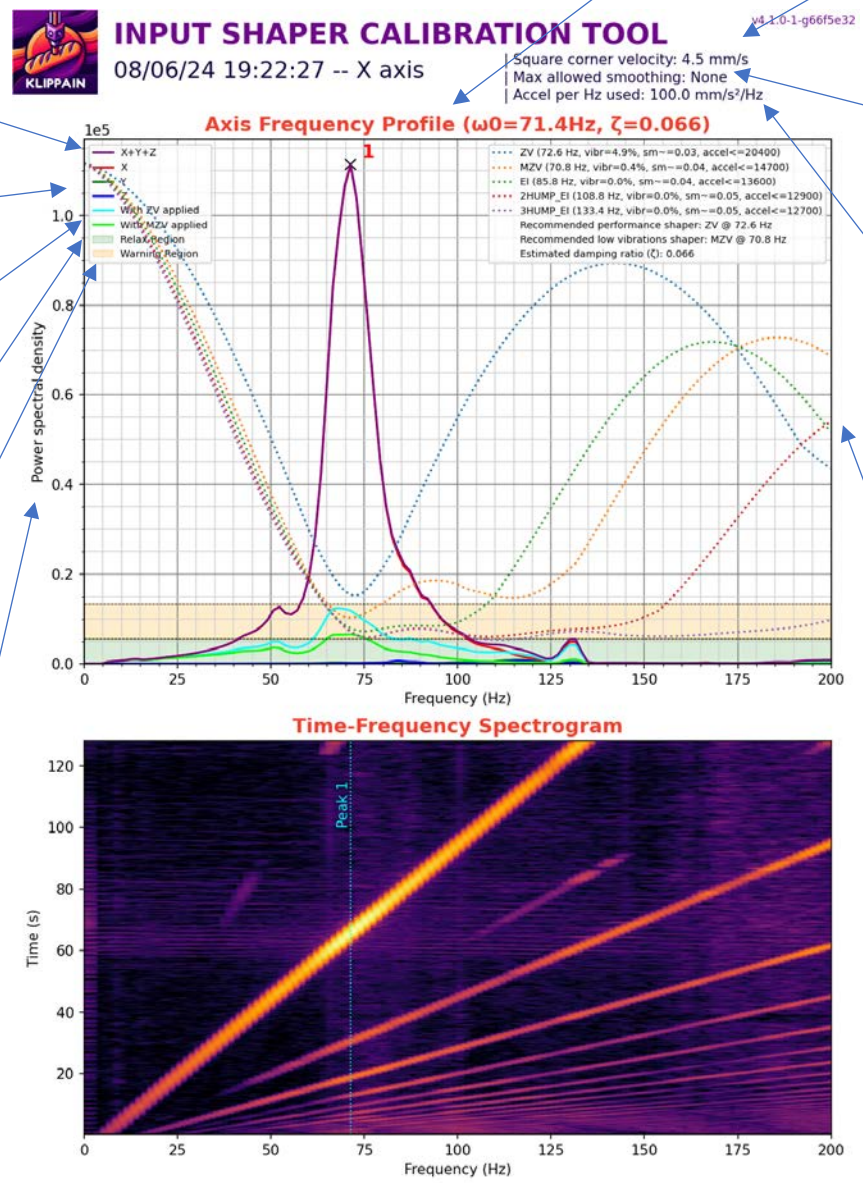
Signals from the three axes of ADXL345

Resulting signal after a shaper (zv or mzv) is applied

Relax region, don't worry to much not as important

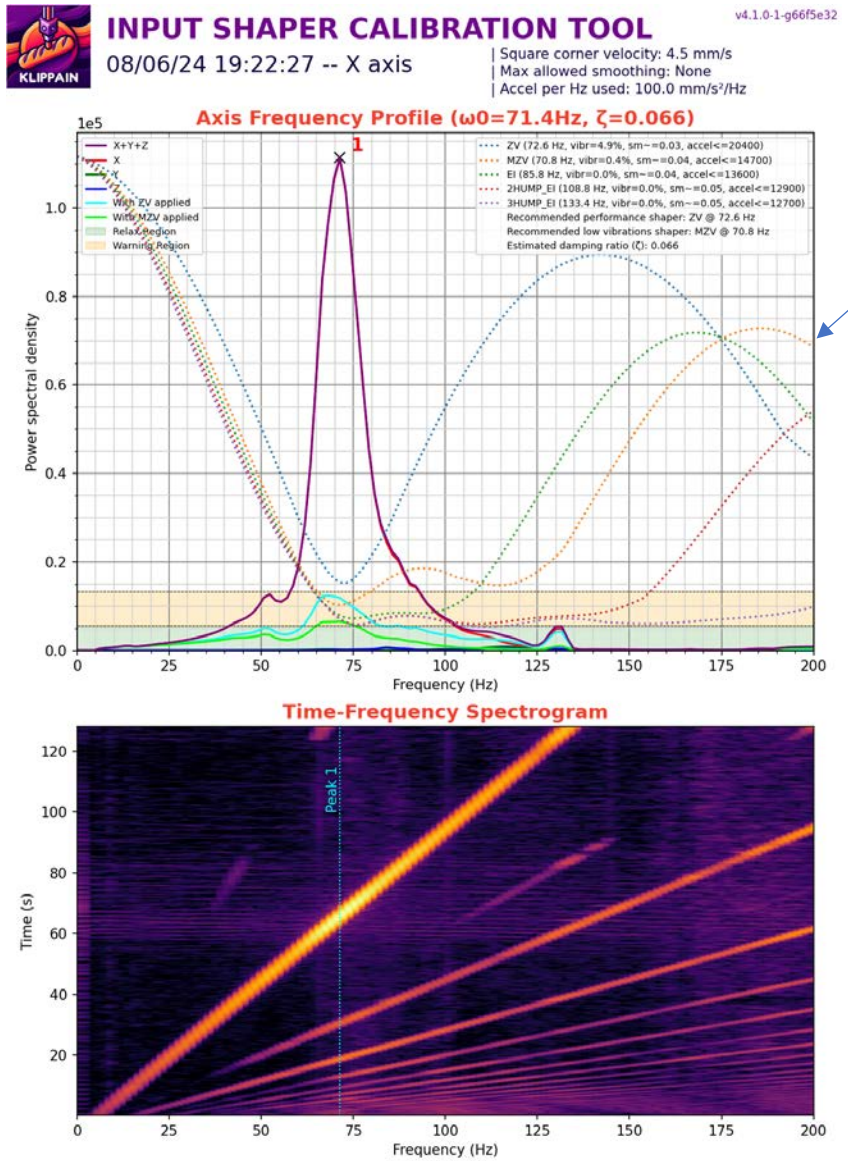
Warning region. Taken as a percentage of max peak value. Could be a problem, or not

PSD (y-axis), the values do not mean much.
Watch out for really low 1e2 and sometimes 1e3, and really high 1e9 ish



Spectrogram is used to see if there are any "ghost vibrations" which may be affecting the graph. Generally used to see if LIS2DW is being used, or for fans

X-input shaper: Closer Look



Shaper Freq

Vibrations remaining after shaper applied

Smoothing from shaper.

Calculated max acceleration based upon shaper

Shaper

Shaper lines

calculated shapers
Don't rely on look at graphs

Damping ratio: can be thought of as this width of the main peak.
Calculated using the half-quadratic gain method.

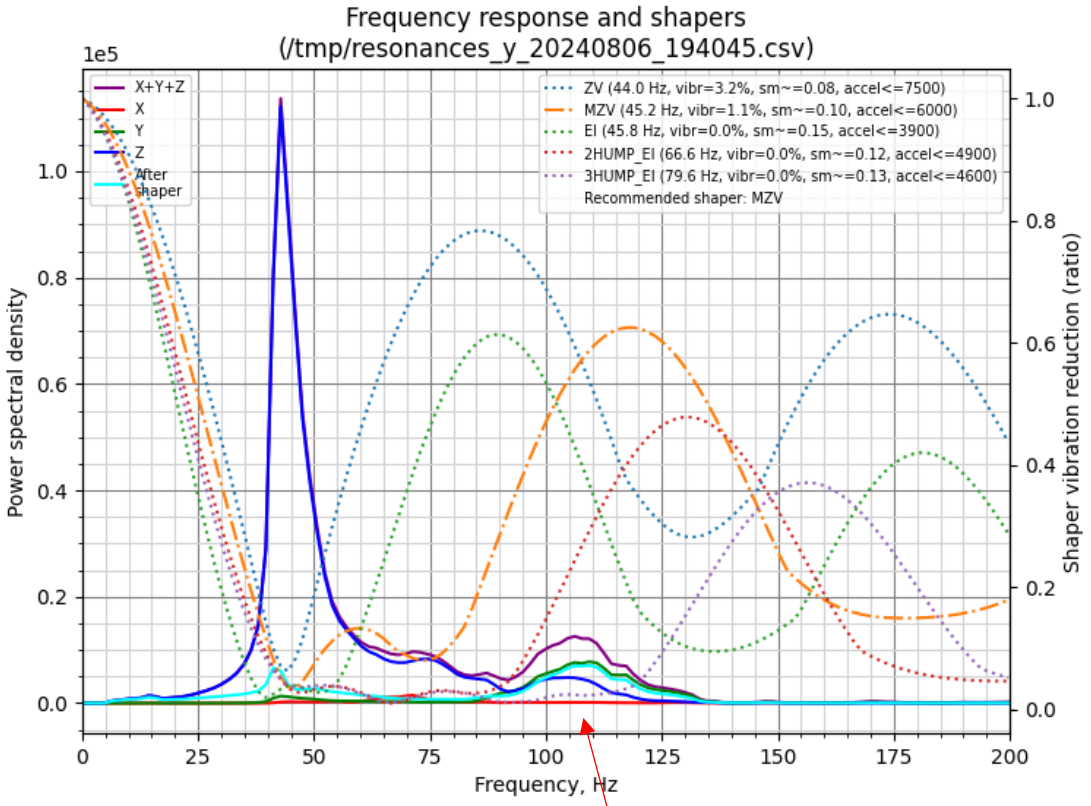
Standard values on V2 and Trident can range from 0.03ish to 0.06ish

If you are over 0.06ish you may have an issue

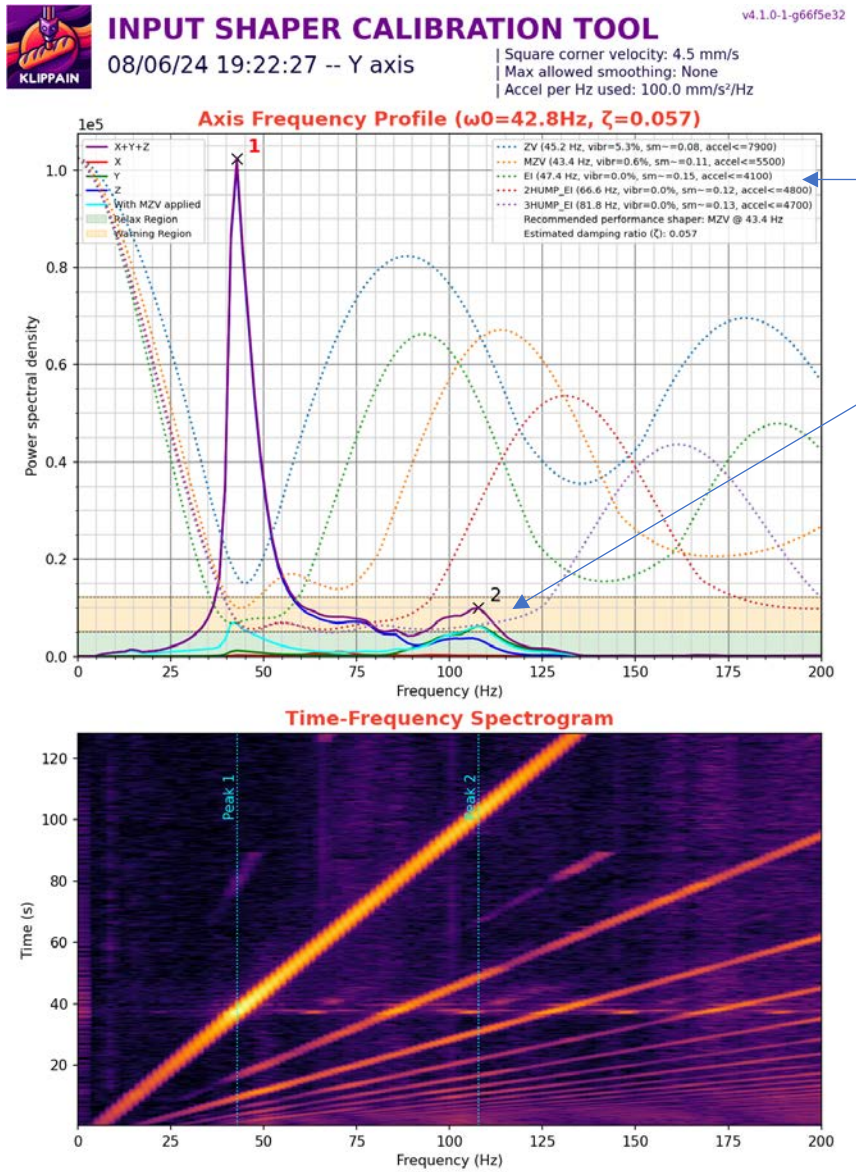
Other printers may have higher values: ender3, etc.

Y – Input Shaper

standard Klipper vs. Shaketune

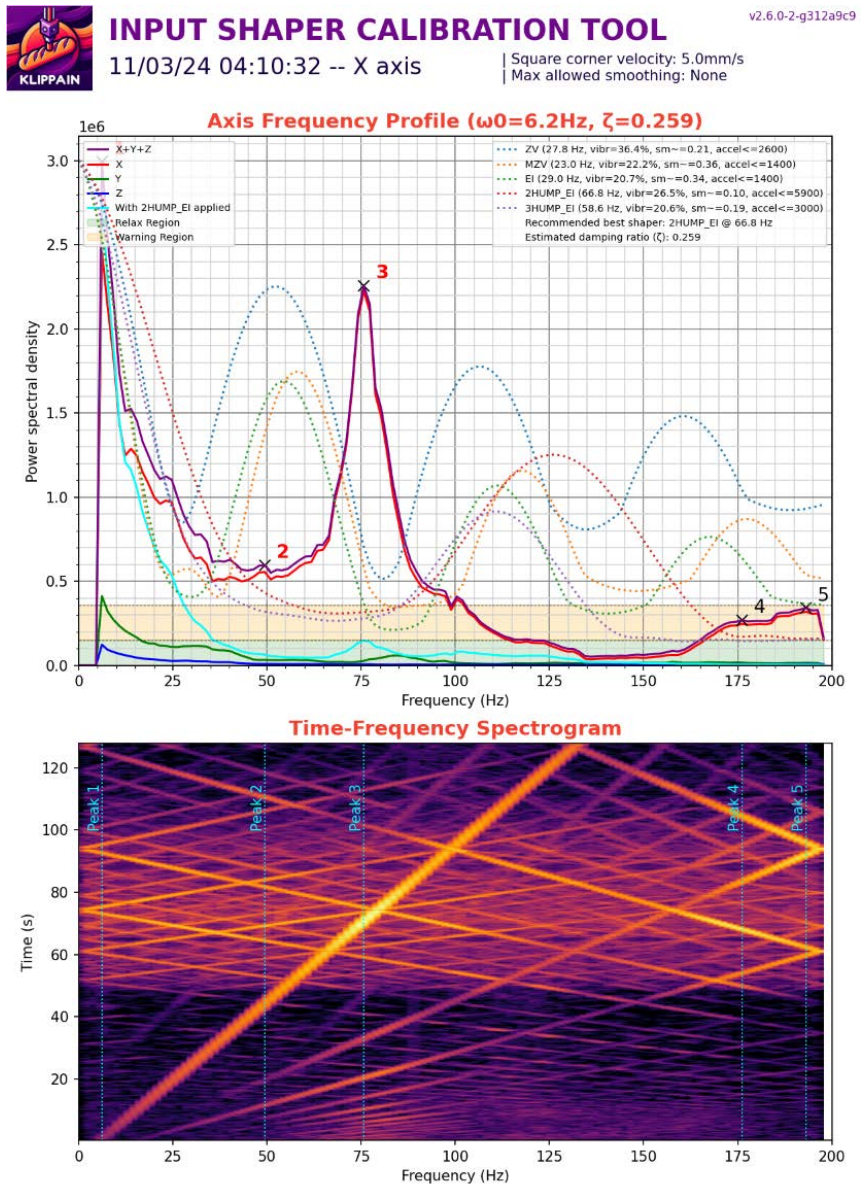


Excessive x-carriage wobble.
Probably need smaller screws or retighten or umbilical or new linear rail carriage



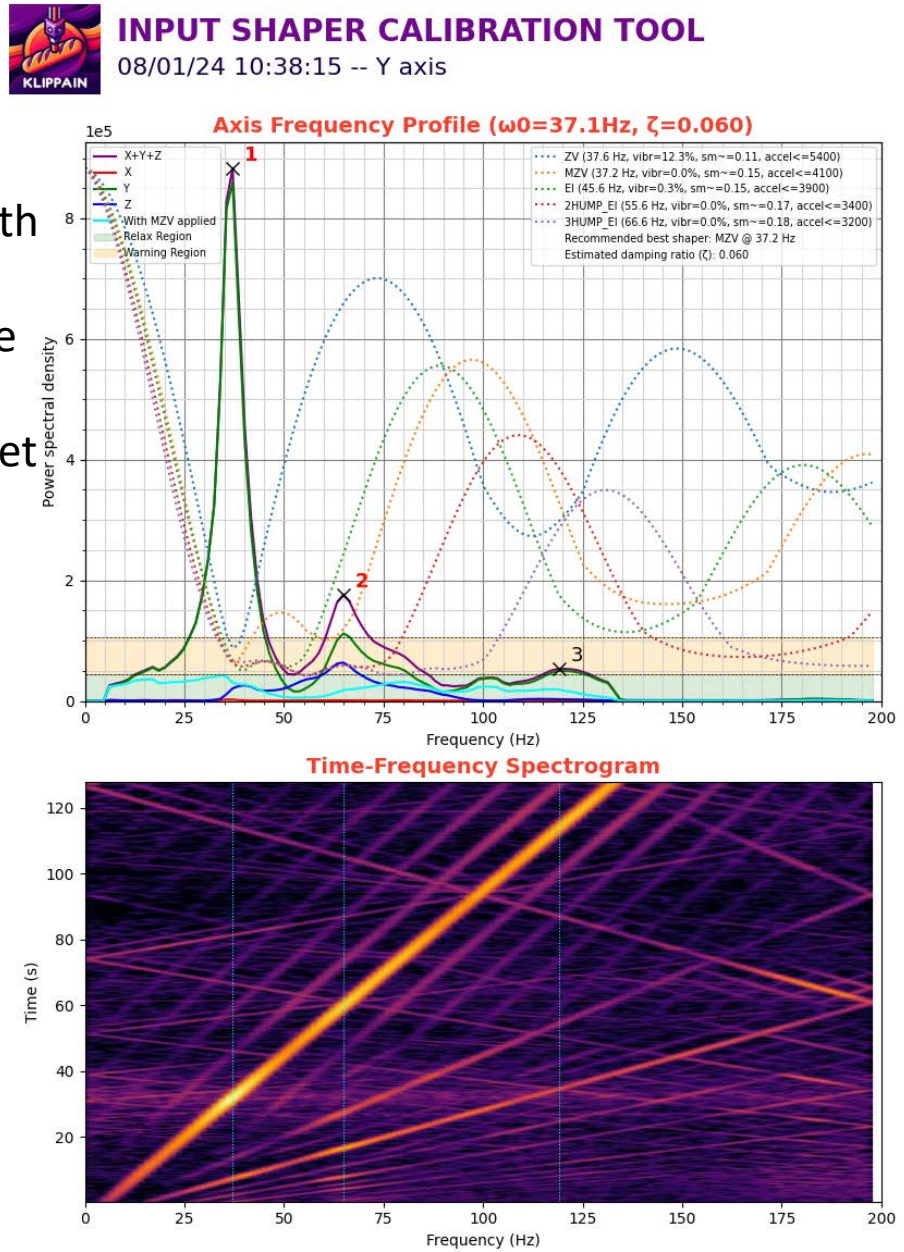
Acceleration should only go down from ZV to 3Hump_EI

Do not use LIS2DW



- Lower sampling rate
- Internal 400 Hz bandwidth non-bypassable filter
- Global offset to the curve which looks like binding
- Can’t determine the offset from the real graph

Aliasing
aka disco light show



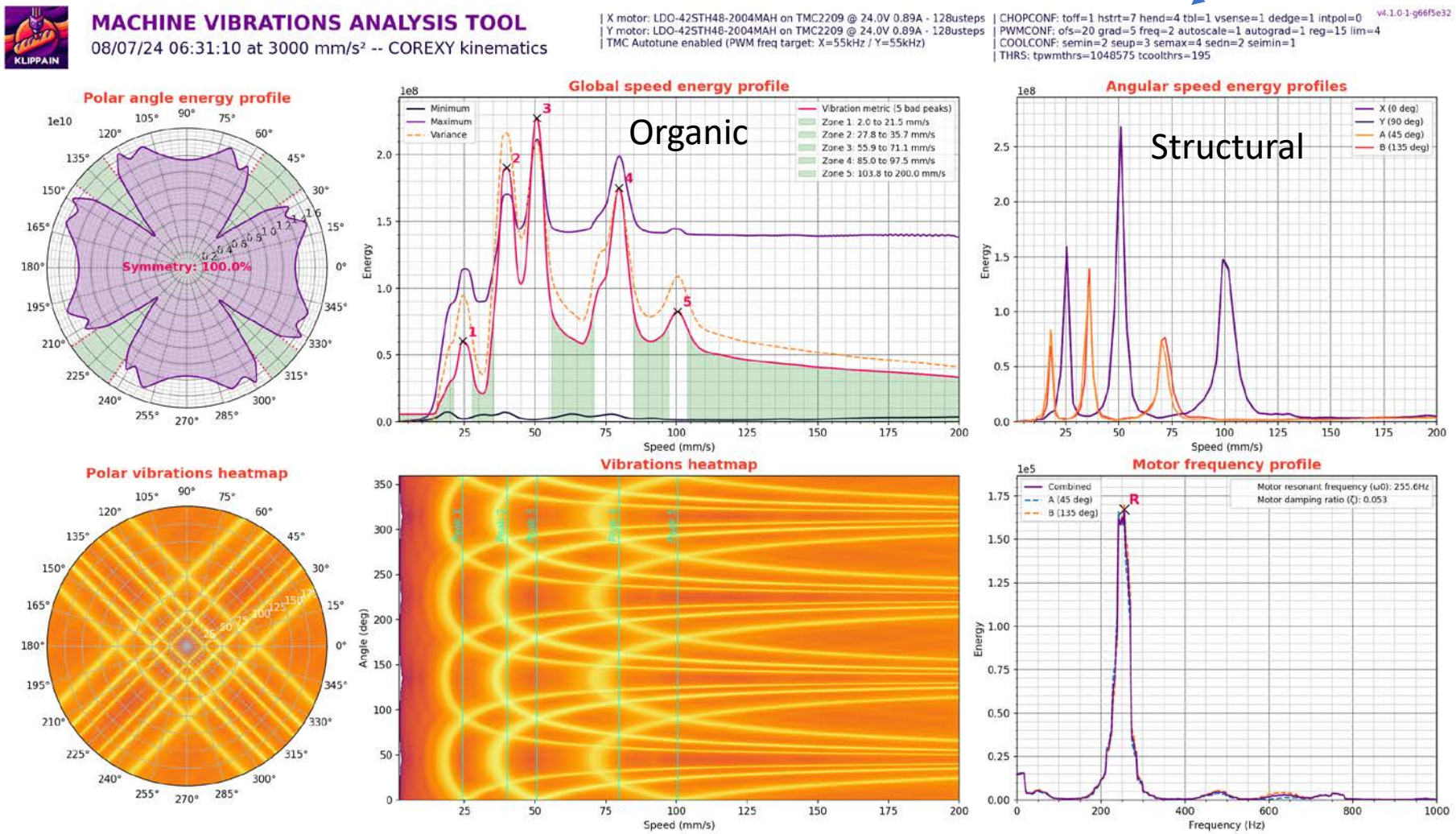
Vibrations Profile

Shaketune specific

Information provided because autotune is installed

Chopper Settings (TMC Driver registers)

Mark up to discuss each graph further



Did a little bit of work on the belts

After tightening belts

There was a slight belt induced racking in A, and B was below 2.0 on PF makes

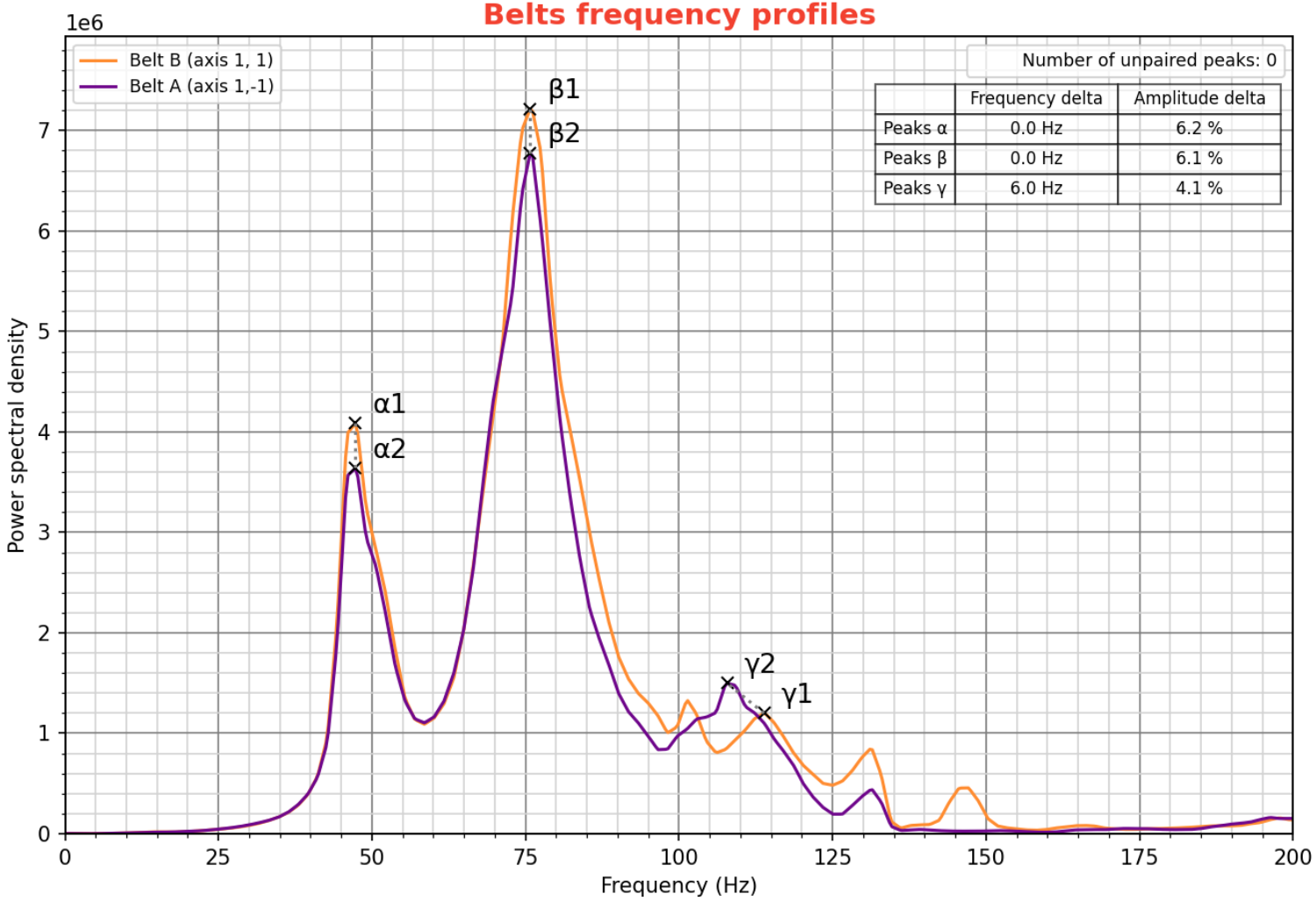
RELATIVE BELTS CALIBRATION TOOL

08/07/24 15:25:14 -- COREXY kinematics

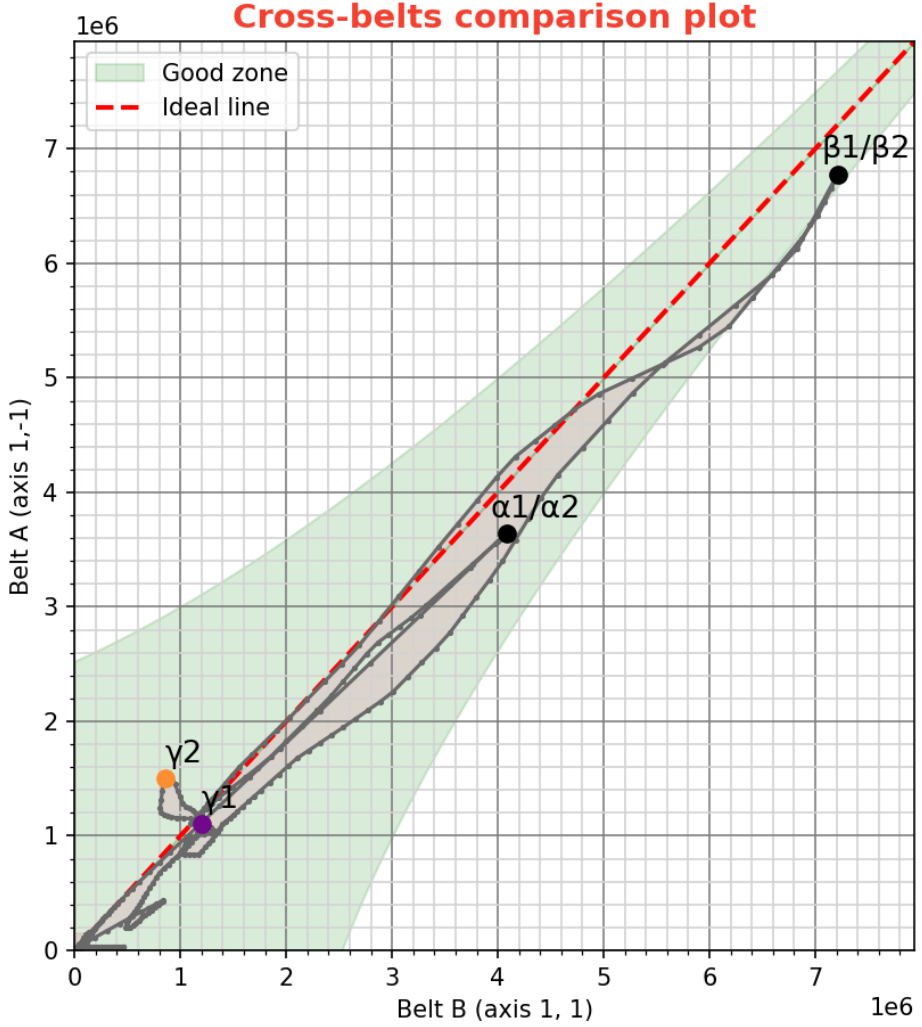
v4.1.0-1-g66f5e32

| Estimated similarity: 99.2%
| Good mechanical health (experimental)
| Accel per Hz used: 100.0 mm/s²/Hz

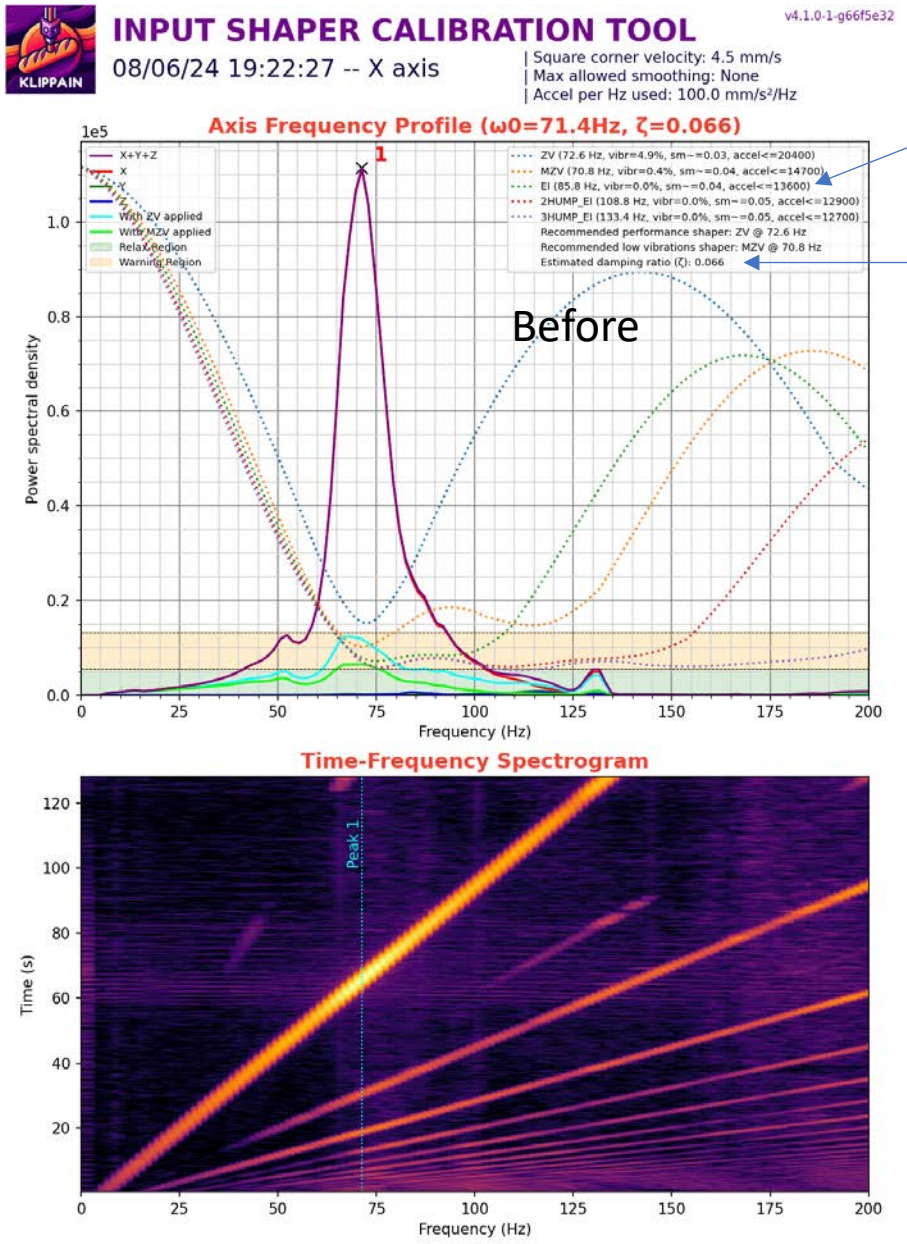
Belts frequency profiles



Cross-belts comparison plot



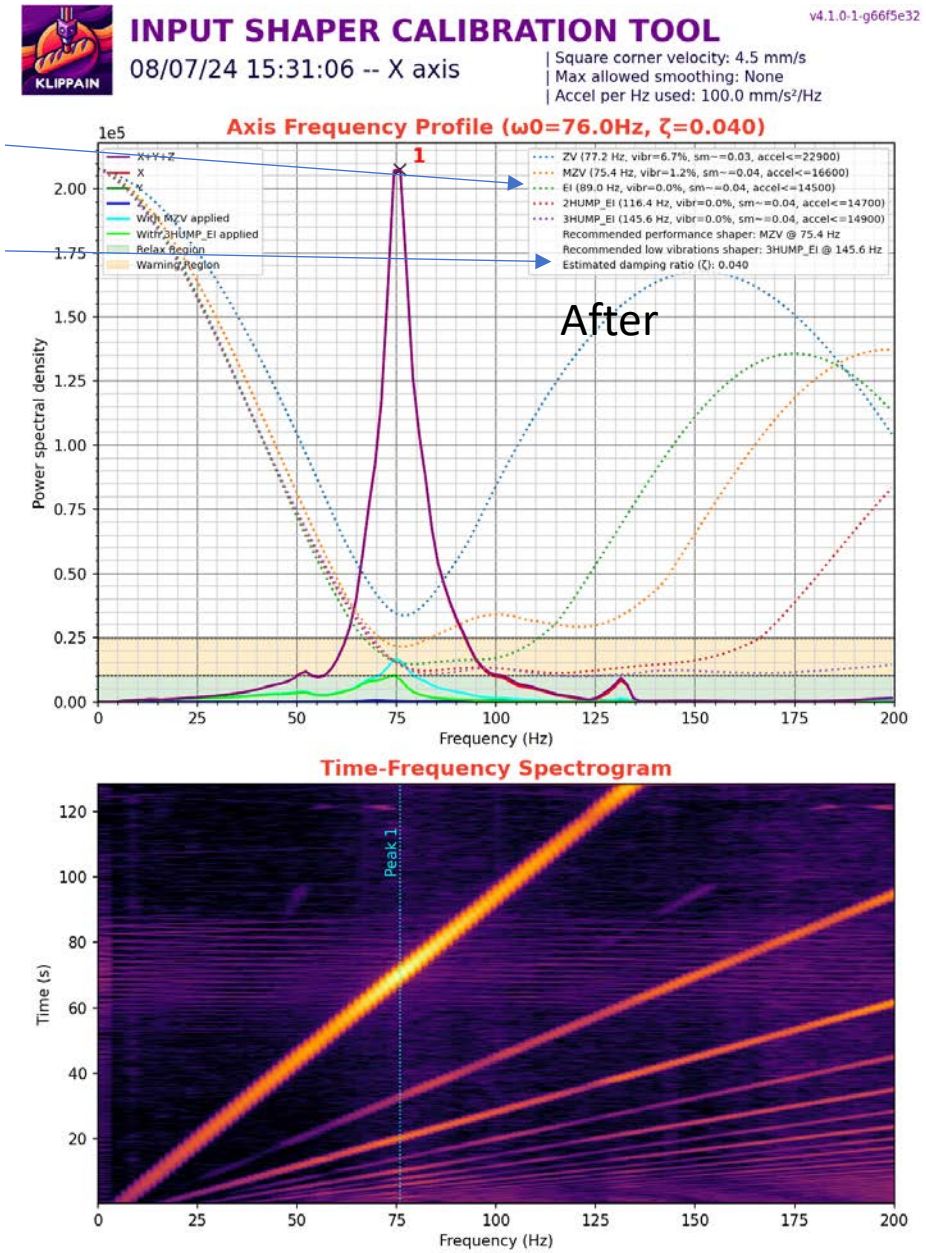
X After tightening belts



Accel is higher by 900

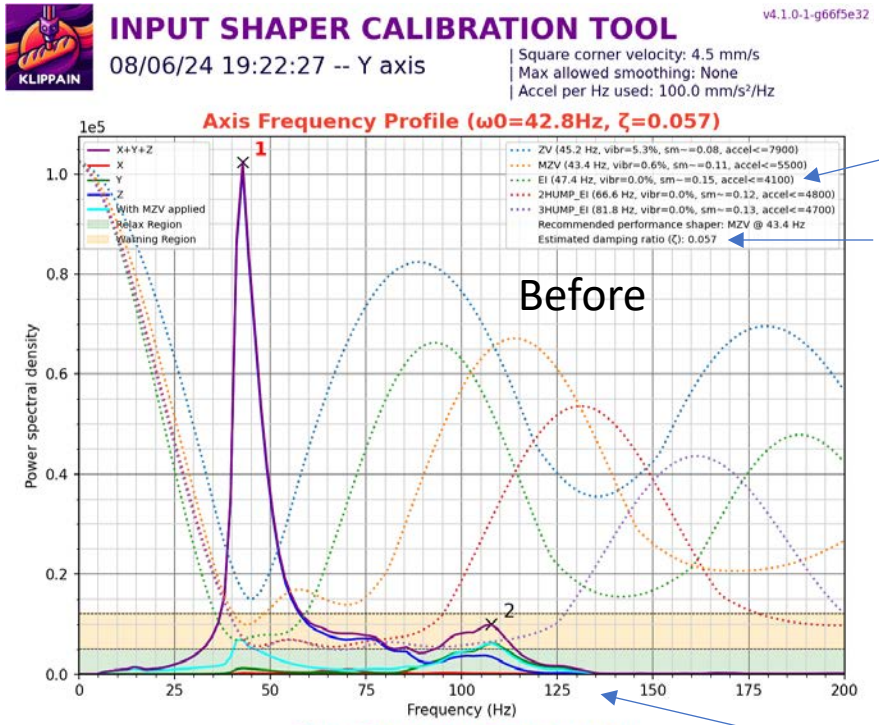
Damping ratio lower

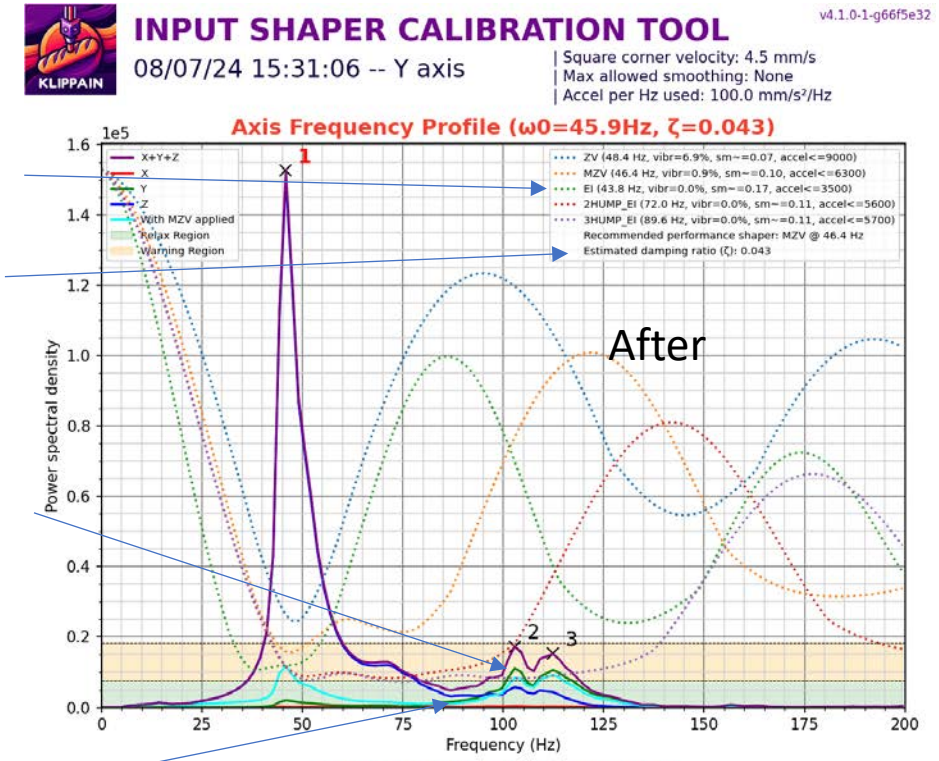
Before



After

Y After tightening belts

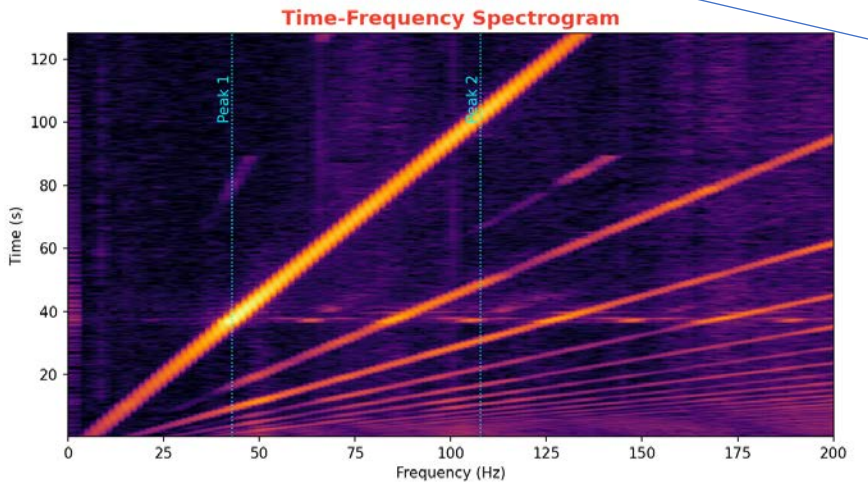


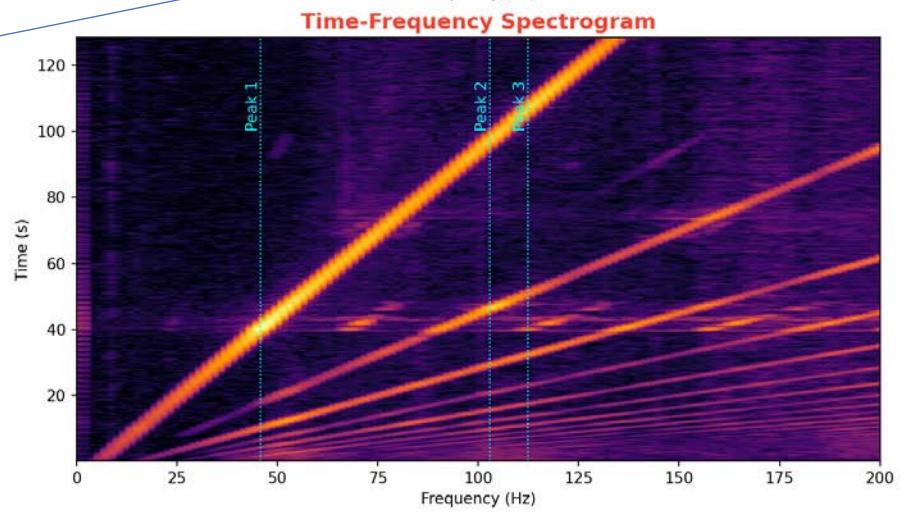


Accel is lower by 600

Damping ratio is lower

As one can see there is some Z rotation.
In this graph green (Y) is actually Z rotation

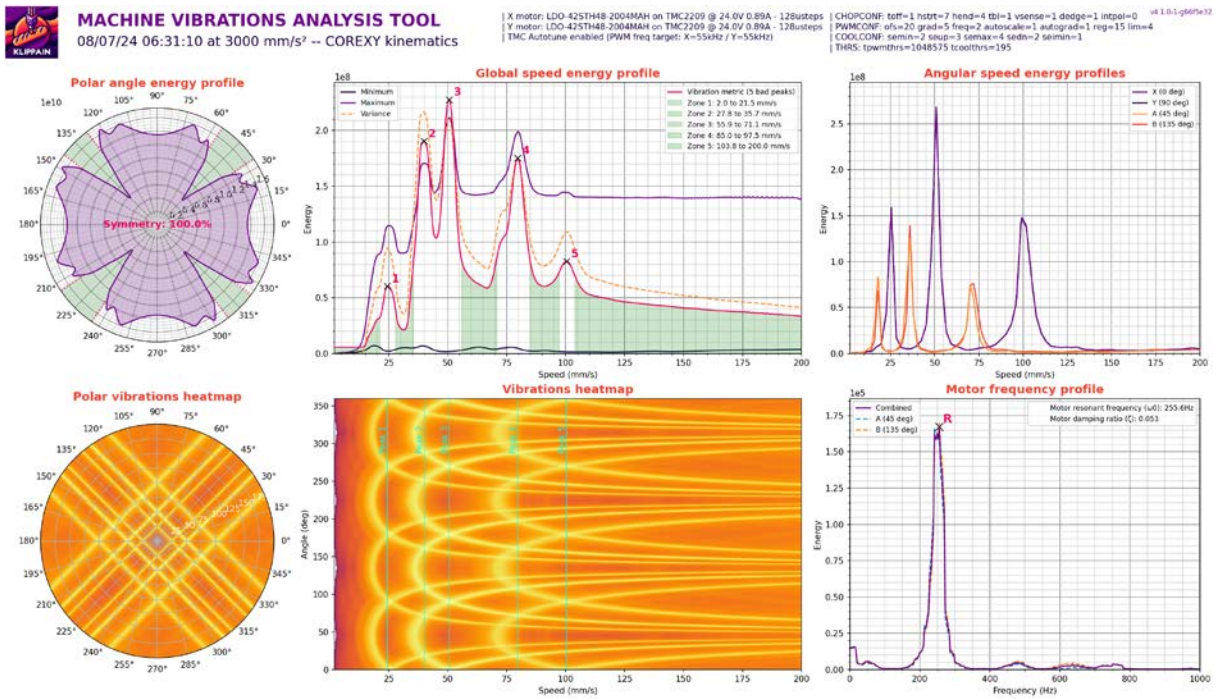




Excessive x-carriage wobble.
Found that my x-axis linear rail carriage rotates around the linear rail.
Solution: new linear rail

Vibrations after tightening Belts

Before



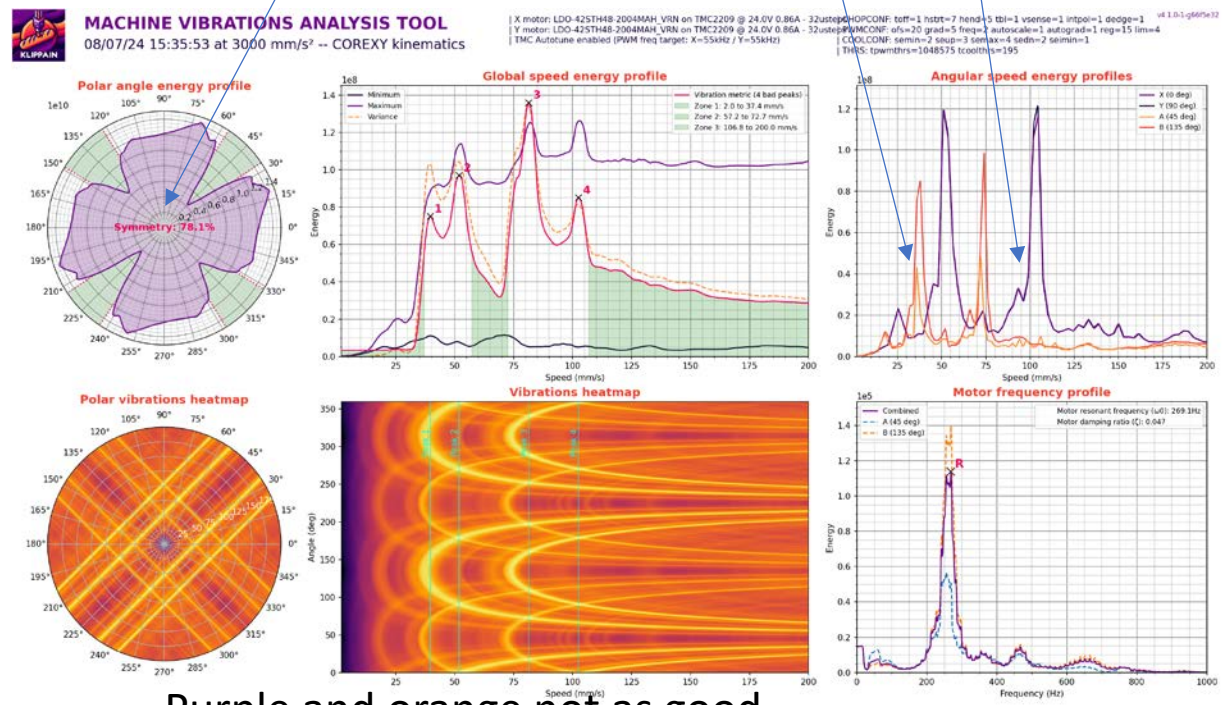
Want more orange

Symmetry is worse

Belt vibrations are not even

More noise

After



Purple and orange not as good

Takeaway: tighter belts are not always the answer. It would be better for me to fix the issues with the x-axis.

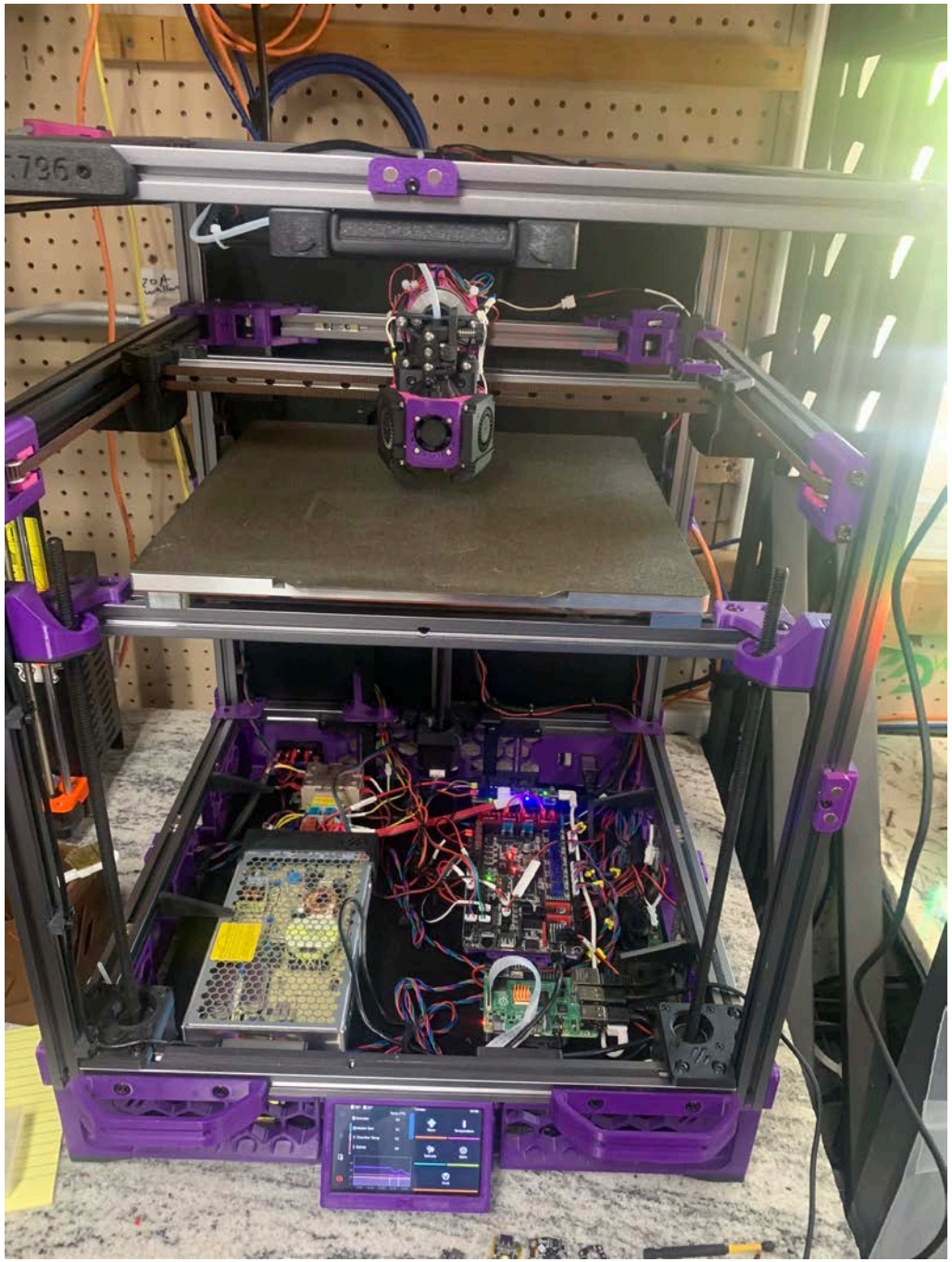
As you have seen while belt input shaper and x-input shaper got better, y-input shaper got a little worse vibrations got a little worse

How do I know it is an issue

- I move the toolhead to see what was moving in Rx rotation.
- You can also excite at freq at the humps in y.

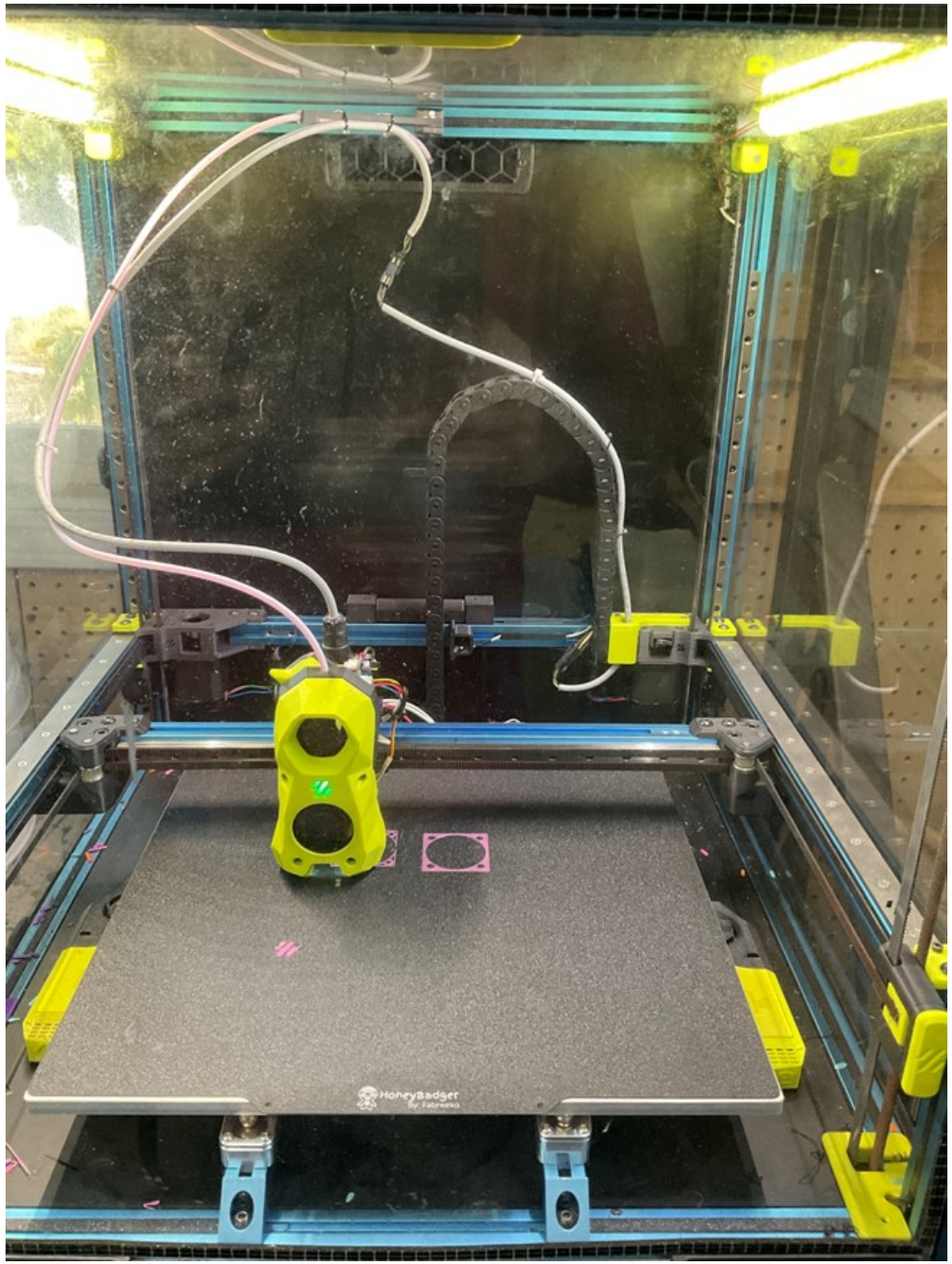
Common Areas for trouble:

please explain



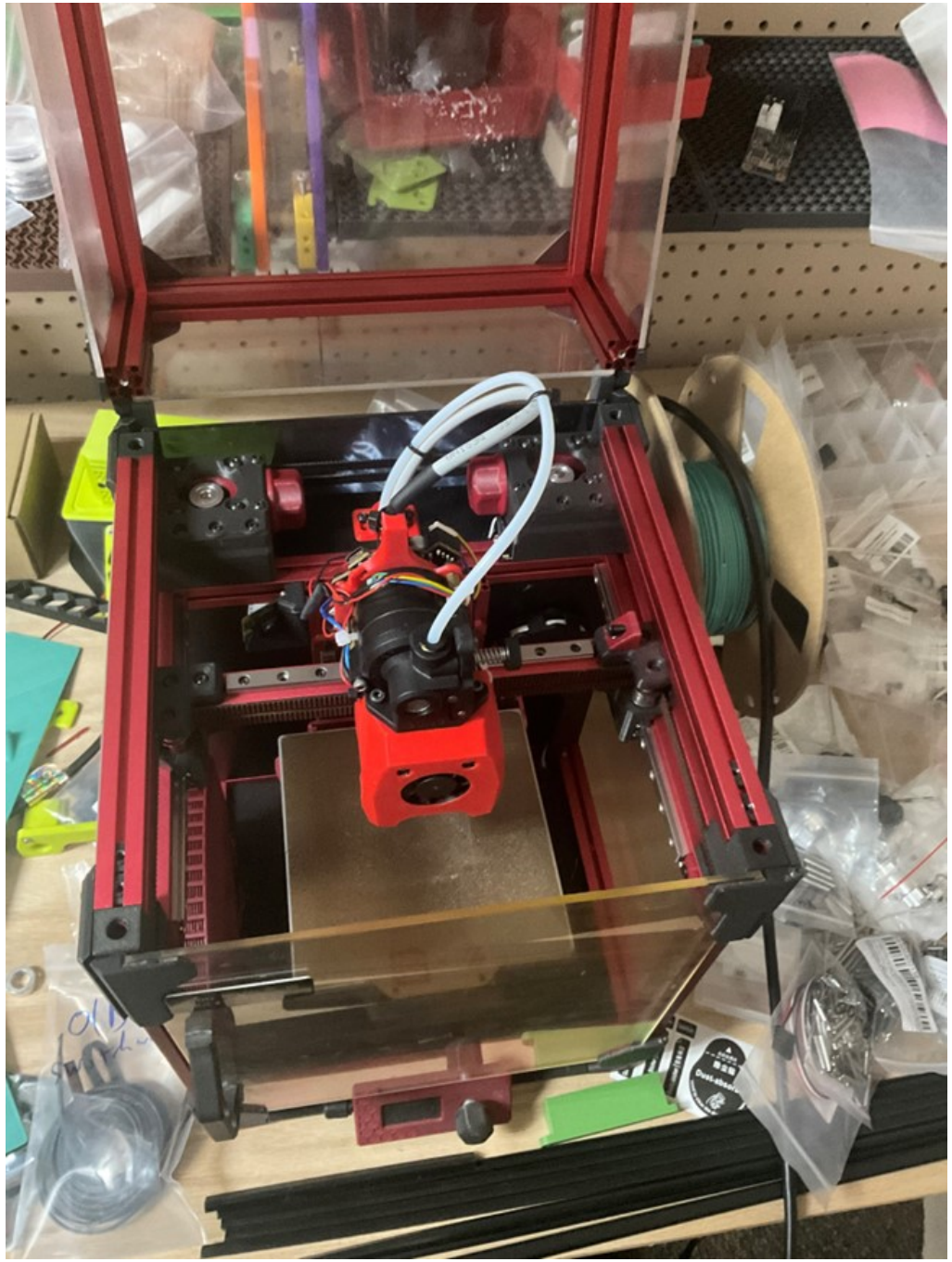
Common Areas for trouble:

please explain



Common Areas for trouble:

please explain



Common Areas for trouble:

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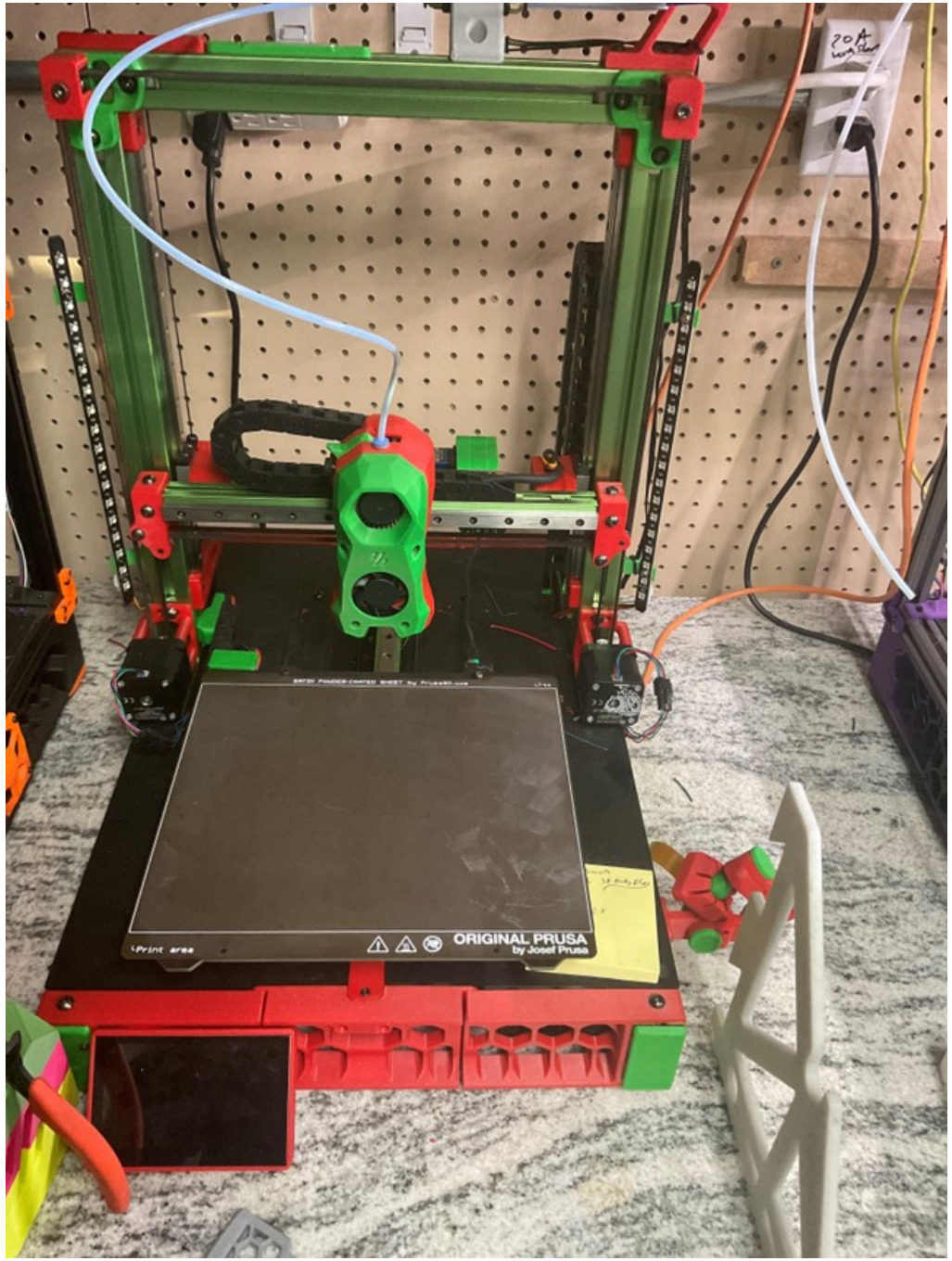

Order of Calibrating

- E-Steps (if not already done)
- Belt shaper
- Input shaper
- Vibrations Profile
- PA – pressure advance
- EM – extrusion multiplier
- Print

Any Questions

Shake tune
Frix_X

Reth's YouTube

TMC_Autotune
AndrewMcGr

3D Printers &
a Whiteboard

PF aka Diyshift Belt
tension tool

Eddie the
Engineer