Board tolerance stack-up

Purpose: Anticipate how fabrication execution will impact the ability of the finished APA to meet established tolerance requirements.

- What was evaluated
- Method
- Some considerations
- Results
- Options

What was evaluated

- Wire to wire spacing in various APA locations
- Plane to plane spacing in various APA locations
- Gap between boards
- Gap between tooth strips.

Note: Some locations like the APA corners have not been evaluated yet, but board machining tolerances have little to no impact in these regions

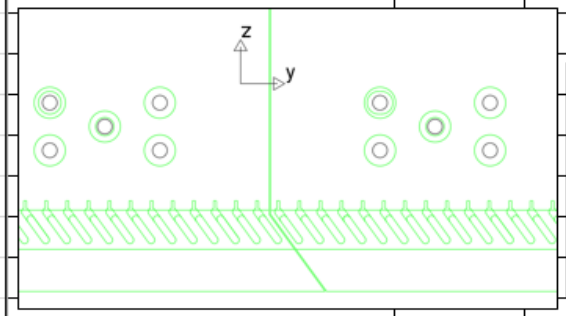
Method

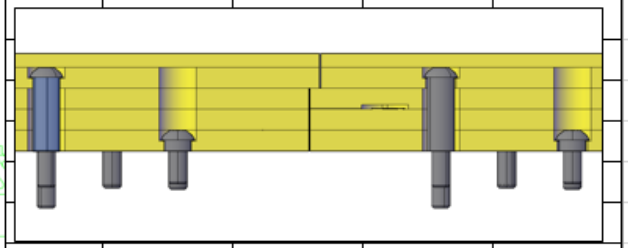
- All tolerances in the path between the two locations of interest were considered.
- The resulting tolerances were summed two ways:
  - Added linearly to establish the outer bound in the extremely unlikely case that all features were fabricated at the limits of tolerance in the direction to maximize positional error
  - Added in quadrature (Root Sum Squared -> RSS) to take advantage of the fact that all features will not be manufactured at limits of tolerance but will follow a statistical distribution with many features closer to the nominals.

Method

Example: Head board gap

Gap between u and v head boards





Contributions to stack up in y from v board

Description	DWG tolerance or spec	Effect on position	Stack-up Tolerance (+/-)
*Hole position in tube	0.250	=t/2	0.125
Tapped Hole pitch diameter	=+/-0.059	=t/2	0.030
Min screw radial clearance	0.022	=t/4	0.006
Screw pitch diameter	=+/-0.045	=t/2	0.023
Screw major diameter tolerance	=+/-0.070	=t/2	0.035
Sleeve ID tolerance	=+/-.025	=t/2	0.013
Min screw radial clearance	0.020	=t/4	0.005
sleeve concentricity	0.025	=t/2	0.013
Pin OD	=+/-0.025	=t/2	0.013
Min clearance	0.000	=c/4	0.000
Hole ID	=+/-0.100	=t/2	0.050
Location of "straight" edge	=+/-0.100	=t	0.100
Total for one board			0.410
Total for two boards			0.820
RSS board to board			0.354

Some considerations

- The RSS method works best for high production in which the statistical distribution of size and location of component features can be characterized.
- It is still reasonable to assume that most often the nominal dimension will be targeted, and the actual dimensions will be distributed about the nominal
- There are exceptions to this. For example, the tooth strip lengths generally run longer than nominal. This is because the part shrinkage rate was less than anticipated when designing the mold.

Results – 100 micron tolerance on board features that control wire and plane spacing and board fit.

Wire spacing – within a board stack

- About 98% of the wire spacing is control by the pins on the molded tooth strips.
- The strips control the wire spacing well within the spacing tolerance.

Summary of results of APA stack up analysis - board accuracy to 100 microns						
	sheet #	Worst case	RSS	Require-ment	Board accuracy contributes	Comments
Within a board stack						
Wire spacing						
Foot x and g	1a	0.09	0.09	0.5	no	
Foot u and v	1b	0.12	0.09	0.5	no	
Side	2	0.12	0.08	0.5	no	
head					*	

Results – Continued

Plane to plane spacing – within a board stack

- Plane to plane spacing on foot and side boards are located by different methods.
- Foot boards - Flathead screws locate the boards. It is difficult to define how well this method will locate. More on up coming slide.
- Side boards - Plane to plane spacing is controlled well between u and v. Based on RSS, v and x and g and u spacing is well controlled unless the frame is bowed to near the limit.
- Head boards – spacing "within a board stack" is well controlled. The effect plane to plane spacing between board stacks has not been analyzed.

Plane to plane spacing						
Foot - new-tool	4a	0.56	0.29	0.5	yes	
Foot - baseline	4b	1.23	0.84	0.5	yes	
Side - u to v	5a	0.51	0.29	0.5	yes	
Side -v/x, u/g no bow	5b	1.02	0.28	0.5	yes	
Side -v/x, u/g w/bow	5c	1.52	0.57	0.5	yes	Very localized effect
Head	6	0.24	0.24	0.5	*	

Results – Continued

Effect of the machining accuracy of the tooth strip locating feature

100 micron – Current tolerance (from previous page)

Plane to plane spacing						
Foot - new-tool	4a	0.56	0.29	0.5	yes	
Foot - baseline	4b	1.23	0.84	0.5	yes	
Side - u to v	5a	0.51	0.29	0.5	yes	
Side -v/x, u/g no bow	5b	1.02	0.28	0.5	yes	
Side -v/x, u/g w/bow	5c	1.52	0.57	0.5	yes	Very localized effect
Head	6	0.24	0.24	0.5	*	

150 micron

Plane to plane spacing						
Foot - new-tool	4a	0.66	0.37	0.5	y	
Foot - baseline	4b	1.33	0.87	0.5	y	
Side - u to v	5a	0.61	0.36	0.5	y	
Side -v/x, u/g no bow	5b	1.12	0.32	0.5	y	
Side -v/x, u/g w/bow	5c	1.62	0.60	0.5	y	Very locatized effect
Head	6	0.24	0.24	0.5	*	

Results – Continued

Wire to wire spacing between board stacks

- There are roughly 42 teeth per tooth strips, so the space between wires is defined across the tooth strip gap approximately 1 out of 42 times
- This gap is influenced by the tooth strip fabrication and how well it is located on the board.
- Other than fit of the board locating holes, this spacing is not controlled by machining accuracy.

Between boards						
Wire spacing						
Foot x and g	7a	1.06	0.50	0.5	no	
Foot u and v	7b	1.30	0.48	0.5	no	
Side	8	0.85	0.34	0.5	no	
head - x and g	9a	0.82	0.35	0.5	*	
head - u and v	9b	0.90	0.41	0.5	*	

Results – Continued

Gaps between boards

- In all cases, this spacing relies on RSS method to show that the spacing tolerance is achievable.
- This spacing is controlled by machining accuracy.

100 micron

Gap between boards						
Foot	10	0.86	0.36	0.4	yes	
Side	11	0.82	0.35	0.4	yes	
Head - straight	12a	0.82	0.35	0.4	yes	
Head - Angled	12b	0.90	0.41	0.4	yes	

150 micron

Gap between boards						
Foot	10	0.96	0.42	0.4	y	
Side	11	0.92	0.42	0.4	y	
Head - straight	12a	0.92	0.42	0.4	y	
Head - Angled	12b	1.04	0.51	0.4	y	

Results – Continued

Gaps between tooth strips

- This spacing is controlled by the accuracy of the tooth strip cut and accuracy of the location of the strip on the board.
- Other than fit of the board locating holes, this spacing is not controlled by machining accuracy.
- The x and g foot strip gap relies on RSS method to show that the spacing tolerance is achievable.
- The tolerance limits defined by the RSS method are .1 mm beyond the gap size u and v strips for the side and foot boards. This indicates it is more likely to occasionally have interference.
- Reducing the length slightly maybe an option, but a larger gap between tooth strips may increase the frequency of catching a wire during winding.

Tooth strip to tooth strip						
Foot x and g	13	1.06	0.50	0.5	no	
Foot u and v	13	1.06	0.50	0.4	no	
Side	14	1.02	0.49	0.4	no	

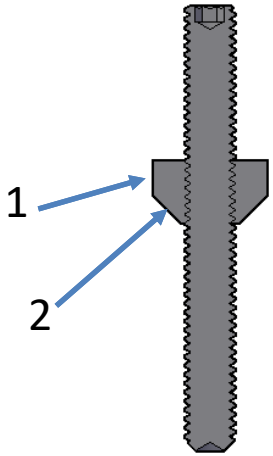
Foot board location

The current design calls for using flathead screws to locate the foot boards. Four screws are used in pairs. The screws pairs are added and remove alternately as the board stack is built up.

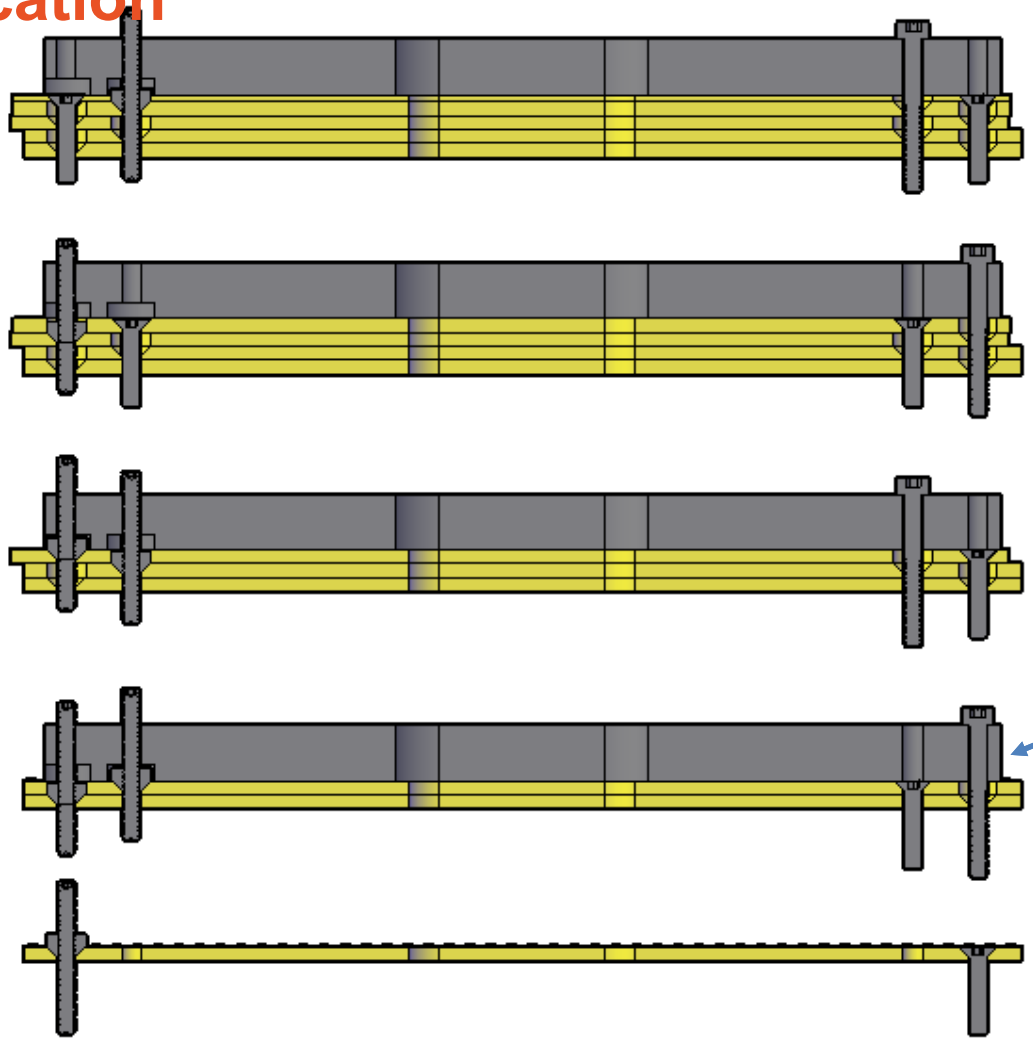
Each board is independently located to the frame tube by the countersunk flathead screw.

New proposal is to line up board to each other more directly with a custom part during this process.

Foot board location



Custom “tool”
Surface 1 and 2 directly aligns board to board



Proposed method with custom alignment tool to align board to board.

Current method with alternating screws

Summary

- The new alignment tool is relatively inexpensive and will result in better positional control of the foot boards.
- Utilizing the RSS methods leads to the conclusion that relaxing the tolerance of the tooth strip locating feature, the shoulder, to 150 microns should still allow control of wire to wire spacing.
- Relaxing the tolerance of the location of the end of the board could lead to occasional interference with the neighboring board. Not sure if reducing the length of the board is possible due to proximity of the end to solder pads and possibly traces.
- Locating hole tolerances in boards should not be relaxed
- Tolerances of features that control the fit of the tooth strips should not be relaxed.
- Frame hole pattern to pattern positional accuracy (to a diameter) of 250microns (+/-125microns). TradeTech has confirmed. Need to confirm with vendor in UK.

Back up slides

Results – 100 micron board accuracy

Summary of results of APA stack up analysis - board accuracy to 100 microns						
	sheet #	Worst case	RSS	Require-ment	Board accuracy contributes	Comments
Within a board stack						
Wire spacing						
Foot x and g	1a	0.09	0.09	0.5	no	
Foot u and v	1b	0.12	0.09	0.5	no	
Side	2	0.12	0.08	0.5	no	
head					*	
Plane to plane spacing						
Foot - new-tool	4a	0.56	0.29	0.5	yes	
Foot - baseline	4b	1.23	0.84	0.5	yes	
Side - u to v	5a	0.51	0.29	0.5	yes	
Side -v/x, u/g no bow	5b	1.02	0.28	0.5	yes	
Side -v/x, u/g w/bow	5c	1.52	0.57	0.5	yes	Very localized effect
Head	6	0.24	0.24	0.5	*	
Between boards						
Wire spacing						
Foot x and g	7a	1.06	0.50	0.5	no	
Foot u and v	7b	1.30	0.48	0.5	no	
Side	8	0.85	0.34	0.5	no	
head - x and g	9a	0.82	0.35	0.5	*	
head - u and v	9b	0.90	0.41	0.5	*	
Gap between boards						
Foot	10	0.86	0.36	0.4	yes	
Side	11	0.82	0.35	0.4	yes	
Head - straight	12a	0.82	0.35	0.4	yes	
Head - Angled	12b	0.90	0.41	0.4	yes	
Tooth strip to tooth strip						
Foot x and g	13	1.06	0.50	0.5	no	
Foot u and v	13	1.06	0.50	0.4	no	
Side	14	1.02	0.49	0.4	no	
Other locations to consider						
Wire spacing						
corner - foot to side boards						
side boards to combs						
corner - side to head						
Plane to plane spacing						
corner - foot to side boards						
side boards to combs						
corner - side to head						
*Wire location depends on solder pad locational accuracy rather than machining accuracy						

Results – 150 micron board accuracy

Summary of results of APA stack up analysis - 150micron tolerance 4a-5c, 10-12b						
	sheet #	Worst case	RSS	Require-ment	Board accuracy	Comments
Within a board stack						
Wire spacing						
Foot x and g	1a	0.09	0.09	0.5	no	
Foot u and v	1b	0.12	0.09	0.5	no	
Side	2	0.12	0.08	0.5	no	
head					*	
Plane to plane spacing						
Foot - new-tool	4a	0.66	0.37	0.5	yes	
Foot - baseline	4b	1.33	0.87	0.5	yes	
Side - u to v	5a	0.61	0.36	0.5	yes	
Side -v/x, u/g no bow	5b	1.12	0.32	0.5	yes	
Side -v/x, u/g w/bow	5c	1.62	0.60	0.5	yes	Very locatized effect
Head	6	0.24	0.24	0.5	*	
Between boards						
Wire spacing						
Foot x and g	7a	1.06	0.50	0.5	no	
Foot u and v	7b	1.30	0.48	0.5	no	
Side	8	0.85	0.34	0.5	no	
head - x and g	9a	0.82	0.35	0.5	*	
head - u and v	9b	0.90	0.41	0.5	*	
Gap between boards						
Foot	10	0.96	0.42	0.4	yes	
Side	11	0.92	0.42	0.4	yes	
Head - straight	12a	0.92	0.42	0.4	yes	
Head - Angled	12b	1.04	0.51	0.4	yes	
Tooth strip to tooth strip						
Foot x and g	13	1.06	0.50	0.5	no	
Foot u and v	13	1.06	0.50	0.4	no	
Side	14	1.02	0.49	0.4	no	
Other locations to consider						
Wire spacing						
corner - foot to side boards					no	
side boards to combs					no	
corner - side to head					no	
Plane to plane spacing						
corner - foot to side boards					yes	
side boards to combs					yes	
corner - side to head					yes	
*Wire location depends on solder pad locational accuracy rather than machining accruacy.						