

Second Bond Stitch Width Model as a Trend Solution for Lead Width Reduction

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Abstract

A well known trend in the semiconductor industry is miniaturization while continuously increasing the number of Input Output (IO) connections. This trend introduces new Wire bonding (WB) challenges in the second bond arena, known as the second bond stitch width. As the stitch width scale gets closer to the lead width, the need to accurately predict the second bond width becomes crucial. In order to answer this new need a JMP (ver.7.0) model for second bond stitch width in correlation to the capillary dimensions and Wire Diameter (WD) is introduced. Different designs with changing geometries were optimized, bonded, and measured for their stitch width responses. Geometries such as: Hole (H), Chamfer Diameter (CD), Tip size (Tip), Face Angle (FA), Outer Radius (OR) and WD are part of the tested matrix. A verification test was conducted and custom capillary designs were produced based on a numerical formulation from the model in order to receive a specific stitch width. These capillary designs were bonded and measured in order to verify the credibility of the stitch width model. An important observation out of few interesting results showed, that the main contributors controlling the second bond stitch width are the WD and Tip. Additionally a stitch width formulation as a function of the main capillary geometries and WD is introduced.

Key words: wire bonding, capillary design, wire diameter reduction, fine pitch leads, and model.

Overview

The demand for miniature devices with a large I/O count has become a fundamental requirement in many assembly houses. This ongoing need has pushed substrate design to have an increasing lead count while at the same time minimization of the lead width. For instance a body size of 30mm with approximately 200, 600 I/O is usually expected to have 0.5mm, 0.2mm maximum lead pitch respectively. If higher I/O is needed an even smaller lead pitch is expected and for today's ultra fine pitch packages they can get as small as 100µm with even smaller stitch width [1; 2]. This high demand for ultra small width of lead pitch has brought the lead width to a near proportion as to the 1st bond pad dimension and in rare cases has been seen as low as 40µm lead width. These extremely narrow leads have brought new challenges into the wire bonding industry particularly in regards to the second bond. If, in the past, the main challenges of the second bond were the adhesion of the stitch, the tail area and the intensity of the tool mark, today new measures (e.g. stitch width) are starting to be an important factor

when optimizing a second bond process. If the stitch width is larger than the lead width it is expected to have degradation in the second bond stitch pull results. The degradation is expected both in the average results and in the stability of the process. As wire bonding is a peripheral process surrounding the die in all directions the stitch direction also is changeable around the die. This peripheral factor in the ultra narrow lead process brings the stitch bond to be outside part of the lead in some parts of the die which in return causes large variations in stitch pull readings. Bonding parameters, wire diameter and capillary geometries are known to have a critical influence on the stitch width. Although bonding parameters and the WD are controllable they still have limitations which are related to the process specification and qualification constraints. Figure 1 demonstrates the first and second bond with two different WD with the same capillary dimensions. The differences in WD introduced here are exaggerated for the example normally it is expected to reduce the wire diameter at the range of 0.1-0.2 mil. As seen it is possible still to receive a similar first bond with different second bond shape (the stitch width reduces with smaller WD).

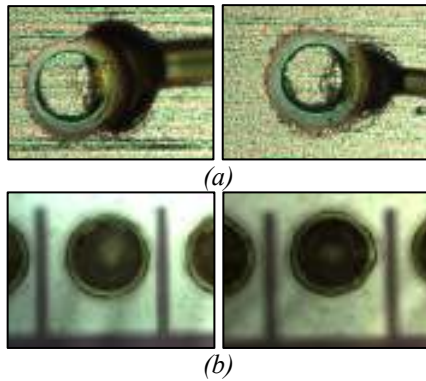


Figure 1: (a) second bond and (b) first bond with same capillary dimension and different wire diameter (from left to right 1.0 and 0.6 mil respectively)

The capillary has numerous geometries that can influence stitch width. Geometries such as Tip, H, CD, FA, and OR are good candidates but also are constrained by the first and second bond specifications. It is therefore clear that in order to efficiently control the stitch width for ultra narrow leads, a method for predicting the stitch width is needed.

The purpose of this study is to find a method of prediction for the stitch width vs. capillary geometry and wire diameter. In order to answer this question a JMP (ver.7.0) model for second bond stitch width in correlation to capillary dimensions and WD was used. Different designs with changing geometries were optimized, bonded, and measured for their stitch width responses. Geometries such as: H, CD, Tip, FA, OR and WD are part of the tested matrix. A verification test was conducted and custom capillary designs were produced based on a numerical formulation from the model in order to receive a specific stitch width. These capillary designs were bonded and measured in order to verify the credibility of the stitch width model.

Experimental Procedure

A set of tests and experiments were produced to find and correlate the capillary design recommendation when a wire diameter is reduced. These experiments were based on basic procedures such as Design of Experiment (DOE) and Plug and Play (P&P) as follows:

Design of Experiment

Design of experiments, (DOE) is the design of all information-gathering exercises where

variation is present. For wire bonding, it is usually used as a method for optimization of first and second bond. The DOE methodology usually practiced by K&S bonding tools is described as follows:

For second bond optimization procedure the main machine's parameters are contact velocity (CV), ultrasonic energy (USG), ultrasonic time (Time), and Force (usually no more than four parameters). When running a central composite model, the test matrix sums up to a total of 26 cells (for four parameters). Measurements of stitch pull, peeling, tool mark and visual inspection is done on a total of 20 balls, 5 balls per axis. Fine Tuning consist of usually 4-6 cells with total of 20 balls, 5 balls per axis. Lastly a confirmation stage is done, usually on three cells (min, max and center process window) with a total of 40 measurements, 10 per axis with similar measurements as in the first DOE stage.

For the first bond optimization procedure main machine parameters are contact velocity (CV), ultrasonic energy (USG), ultrasonic time (Time), Force, and free air ball (FAB) (usually no more than 4 parameters). When running a central composite model, the test matrix sums up to a total of 26 cells. Measurements of Ball size, Ball Height, Ball shear and visual inspection are done on a total of 20 balls, 5 balls per axis. Fine Tuning consist of usually 4-6 cells with total of 20 balls, 5 balls per axis. Lastly a confirmation stage is done, usually on three cells (min, max and center process window) with a total of 40 measurements, 10 per axis with similar measurements as in the first DOE stage.

Plug & Play test vs. Process Optimization

When comparing numerous designs there are two options for comparison: the first consists in running each design in the Optimal Process Window (OPW) done by DOE. The second method consists in running all designs on a reference OPW. The second option is also referred to as Plug and Play test (P&P). While the first options has the clear advantage of maximizing the design output in respect to the process specification, adding the parameter as a variable reduces substantially the ability to observe any ultrasonic differences between the designs. Therefore for this study a combination of both P&P and OPW was chosen as a solution to study the differences between designs and later find the maximum potentials respectively.

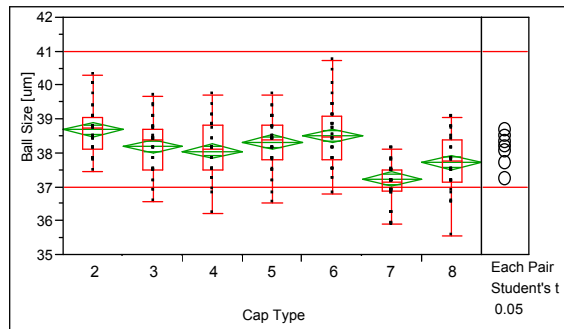


Figure 2: P&P example of a JMP software output graph. Design #2 is the reference design which underwent a DOE to receive OPW. Circles in the right are t-student comparison between each pair design with a confidence level of 95%.

An illustration of a P&P comparison output of multiple designs is seen in Figure 2. It is important to note that only the reference design (#2) which underwent a full DOE is inside the process specification. All other designs are outside specification, which indicates ultrasonic behavior shift compared to the reference design.

Stitch width model

A comparison between a combination of wire diameter and capillary geometries was made to find their influence over the stitch width. Each design underwent a regular wire bonding responses measurements, (e.g. stitch pull, shape, Shear, and 1st bond strength), and additional measurements of stitch width for both x and y axis. The supplement width measurement for each axis was made due to the asymmetric ultrasonic transfer produced by the transducer.

Figure 3 illustrate the stitch width and stitch length

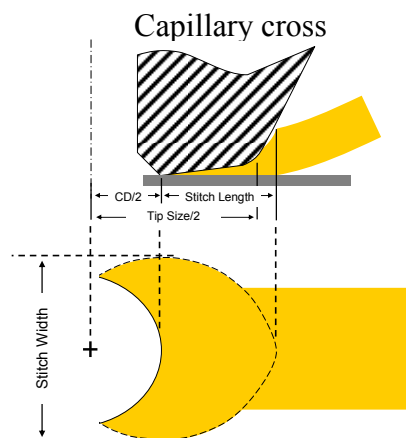


Figure 3: sketch of stitch width and length correlated to the capillary geometry

As seen in figure 3 ,the capillary geometries related to the second bond dimensions on its Chamfer Diameter (CD), Face Angle (FA), Outer Radius (OR), Bottle Neck angle (BTNKa), and Tip size (Tip). Variations of these geometries were run while noting the stitch width and adding into statistical software (JMP v7.0). From the JMP software a linear effect screening model was created with statistical confidence of 95% hence Stitch Width Model (SWM).

Based on the SWM, a verification wire bonding test was conducted with a set of capillary designs bonded with different wire diameters (see Table 1). As Wire Diameter (WD) is limited to the capillary geometry, namely Hole to WD clearance, each design was tested on a different set of WD.

Table 1: Capillary designs for verification test of SWM. (a) Design geometries, and (b) the predicted stitch width [μm] per its WD [mil], and the different WD set to be tested on each design [mil].

(a)						
Design	Hole [mil]	CD [mil]	Tip [mil]	FA [deg]	OR [mil]	ICA [deg]
50μm	1.3	2.2	4.0	11	0.5	90
40μm	1.2	2.1	3.5	11	0.5	90
30μm	1.2	2.2	3.5	11	0.3	90

(b)		
Design	Predicted stitch width [μm] on a WD [mil]	WD to be tested
1	51, 1.0	0.9, 1.0, 1.1
2	38, 0.9	0.8, 0.9, 1.0
3	33, 0.8	0.8, 0.9, 1.0

Each design underwent a second bond DOE over a K&S Maxum Ultra machine with QFP 68LD K&S test device. P&P test was run for each design with its set of WD. Stitch pull and Stitch Width responses were noted and compared for each design.

Results and Discussion

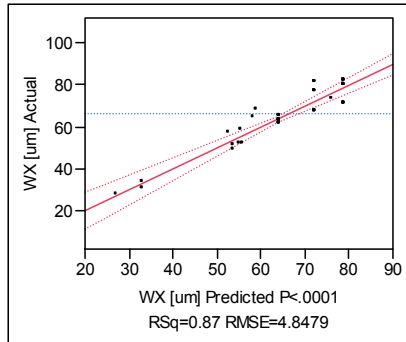
Stitch Width Model

A matrix of designs were tested for their stitch width over x and y axis.

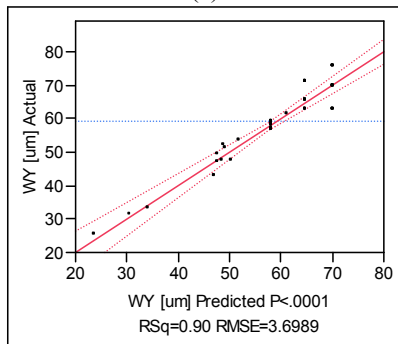
Table 2 shows the matrix of designs used for the modeling of the stitch width relative to the capillaries geometries and WD used. The responses for this matrix were the average stitch width in both X and Y axis. For simplicity the average stitch width was noted as W_x and W_y for X and Y axis respectively.

Table 2: Capillary matrix range of the tested designs.

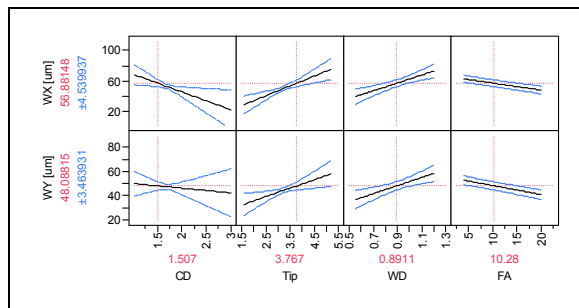
Capillary geometry ranges		
CD	[mil]	0.8 to 2.3
Tip	[mil]	1.6 to 5.2
OR	[mil]	0.1 to 1
WD	[mil]	0.55 to 1.2
FA	[deg]	4 to 20
ICA	[deg]	90



(a)



(b)



(c)

Figure 4: (a) and (b) Confidence for a linear prediction by the JMP software for x and y axis and (c) the trends of stitch width vs. the main input parameters.

A linear screening model was conducted and showed a good correlation (95% confidence) to the width response. From this model, it was found that out of the input parameters tested, the first main

parameters influencing the stitch width are WD, Tip, CD, and FA, (in order of importance order.) Figure 4 shows the confidence for a linear prediction by the JMP software and the trends of stitch width vs. the main input parameters as previously defined. As seen for a larger WD and Tip, it is expected to receive larger stitch width for both x and y axis while the opposite is true for FA. CD however clearly has an influence over the stitch width but its trend is not as clear due to the lower confidence level found by the JMP software, as is indicated by the wider confidence range in the CD column (Figure 4c).

A predicted formula extracted from JMP software can be seen in the equation (1) & (2) for W_X W_Y respectively. As mentioned before the formula was received by JMP software with a confidence level of 95%.

$$(1) \quad W_X = 6.53 + (-23.22) * CD + 12.90 * TIP + 51.85 * WD + (-0.92) * FA$$

$$(2) \quad W_Y = 5.52 + (-3.84) * CD + 6.94 * TIP + 33.45 * WD + (-0.74) * FA$$

Stitch Width Verification Wire Bonding Test

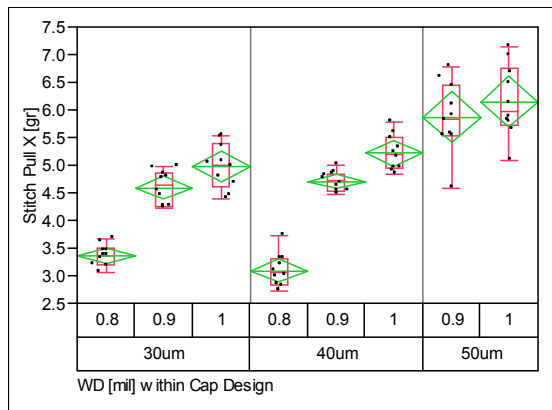
Based on this model, a second phase was conducted to verify the validity of this model in comparison to a specified capillary design and WD.

Table 1 (a) and (b) demonstrates the three designs and their corresponding wire diameter for testing. The output for each design was the stitch pull, width per wire diameter. Each design was optimized on its conventional recommended wire diameter. Naming of each design was based on the predicted width expected from the model with combination of wire diameter (e.g. 50um design from Table 1 indicates that for 1.0mil WD it is expected to receive a 50um stitch width).

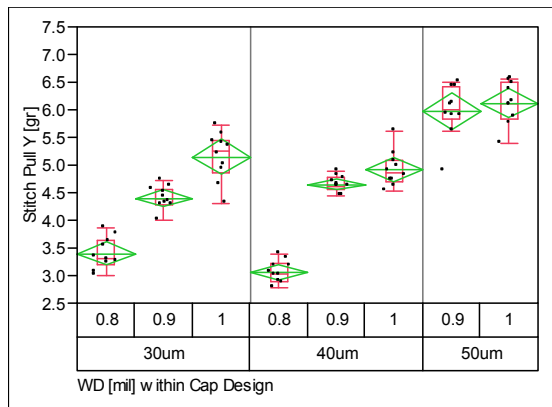
The paragraphs below demonstrate the results for each design (50um, 40um and 30um). Figure 5 illustrates the stitch pull results in correlation to the various WD tested. Figure 6 illustrates the actual stitch width measured for each design and the predicted stitch width based on the formulation in equation (1) & (2). These results were compared and shall be discussed in more details in the discussion paragraph. As the wire diameter was found to be an important factor for the stitch width output an additional correlation was tested between the stitch width and the WD. This connection between WD and Stitch width was calculated by a ratio between the actual average stitch width divided by the WD and noted in Figure 6.

Design	WD [mil]	Axis	Stitch pull [gr]			
			Min	Max	Average	Std
30μm	0.9	X	3.1	3.7	3.4	0.2
		Y	3.0	3.9	3.4	0.3
	1	X	4.2	5.0	4.6	0.3
		Y	4.0	4.7	4.4	0.2
	1.1	X	4.4	5.5	5.0	0.4
		Y	4.3	5.7	5.2	0.4
40μm	0.9	X	2.7	3.7	3.1	0.3
		Y	2.8	3.4	3.1	0.2
	1	X	4.5	5.0	4.7	0.2
		Y	4.5	4.9	4.7	0.1
	1.1	X	4.8	5.8	5.2	0.3
		Y	4.5	5.6	4.9	0.3
50μm	0.9	X	4.6	6.8	5.9	0.6
		Y	4.9	6.5	6.0	0.5
	1	X	5.1	7.2	6.2	0.7
		Y	5.4	6.6	6.1	0.4
	1.1	X	4.6	7.8	6.3	1.0
		Y	5.5	6.7	6.2	0.3

(a)



(b)



(c)

Figure 5: Stitch pull vs. wire diameter in (a) actual results and JMP graphs of (b) X and (c) Y axis

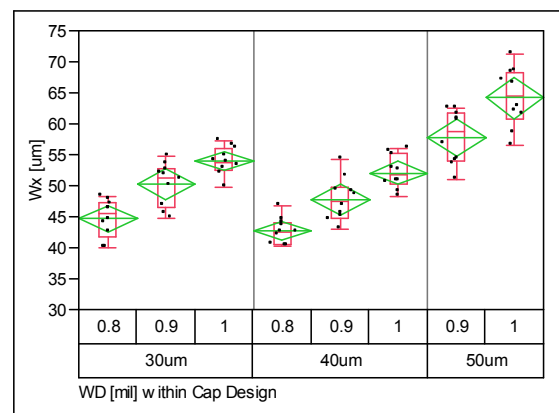
It can be seen in Figure 5 that the stitch pull degrades with smaller WD. This finding correlates to the smaller wire cross section with a relatively lower braking load. Additionally it can be seen that the capillary has an additional effect on the stitch

pull which is mainly attributed to the different Tip (4 vs. 3.5 for design 50μm vs. 40μm and 30μm respectively). Other geometries such as OR, and CD have an influence on the stitch pull but in comparison to the WD and the Tip they are relatively smaller.

The stitch width measurements (seen in Figure 6) were compared to the predicted width both for the X and the Y axis. A relative gap between predicted and measured is showed to range between -28% to 13% depending on the design and the axis. The X-axis shows higher stitch width values and also a higher gap between the predicted and the measured stitch width. This finding might be correlated to the fact that the stitch width is also largely dependent on machine ultrasonic parameters in particular for X-axis. The ultrasonic dependency is larger for the X than for the Y axis due to the non symmetrical direction of the ultrasonic energy which yields a higher squash on the X-axis hence producing a larger width for a given ultrasonic parameter.

Design	WD [mil]	Axis	Stitch width			
			Predicted [μm]	Measured Average [μm]	Predicted vs Measured [%]	Measured to WD ratio
30μm	0.9	X	32	44.7	-28%	2.2
		Y	40	37.3	7%	1.8
	1	X	37.1	50.2	-26%	2.2
		Y	43.3	41.6	4%	1.8
	1.1	X	42.3	54	-22%	2.1
		Y	46.7	44.8	4%	1.8
40μm	0.9	X	34.3	42.7	-20%	2.1
		Y	40.4	35.7	13%	1.8
	1	X	39.5	47.7	-17%	2.1
		Y	43.7	40.1	9%	1.8
	1.1	X	44.6	52.1	-14%	2.1
		Y	47.1	42.8	10%	1.7
50μm	0.9	X	43.6	57.8	-25%	2.5
		Y	46.8	43.4	8%	1.9
	1	X	48.8	64.2	-24%	2.5
		Y	50.1	48.7	3%	1.9
	1.1	X	54	64.2	-16%	2.3
		Y	53.5	52.8	1%	1.9

(a)



(b)

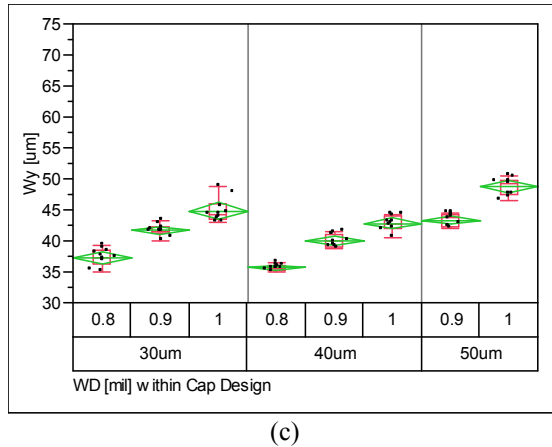


Figure 6: Stitch width vs. wire diameter based on (a) model equation (1) & (2) and JMP graphs of actual results for (b) X and (c) Y axis

Discussion

Stitch Width Model and WD Correlation to the Actual Stitch Width and Wire Pull

Our results have shown the methodology of acquiring a stitch model using the JMP statistical software. A predicted formula for the average stitch width was introduced both for X and Y axis. Comparing the predicted results to the actual measured results showed a gap range of 15-30% lower and of 1-10% higher for X and Y axis respectively.

As a general rule it is known that the stitch width in the X-axis is in most cases larger than the stitch width received in the Y-axis. This rule is related to the transducer movement during wire bonding. In Y-axis the transducer is moving in the longitudinal direction of the second bond while the in X-axis the transducer is moving in a perpendicular direction to the second bond. This substantial difference makes the stitch width in the X-axis much more sensitive to the dynamic ultrasonic parameters. As noticed the higher stitch width seen for the X-axis might be contributed to the influences of the machine parameters which vary from one application to the other. **Figure 7** illustrates the differences expected to get in terms of stitch width for both X and Y axis.

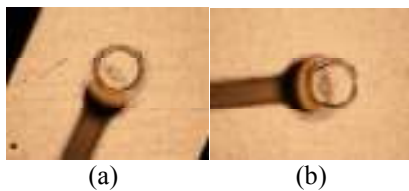


Figure 7: Stitch images of 1.1mil gold wire in (a) Y-axis and (b) X-axis illustrating the larger stitch width received for X-axis.

In addition to SWM the WD to stitch width ratio is in the ranges of 1.9-2.5, 1.7-2.1, and 1.8-2.2 for 50um, 40um, and 30um respectively. This result can be generalized as a simple thumb rule for an expected stitch width vs. WD. Based on this assumption, for a given WD with its standard recommended K&S capillary geometries¹ it can be expected to receive a stitch width in the range of 1.7 to 2.5 times WD. For example equation (3) demonstrates the average stitch width range expected of 60um BPP with 1.0mil WD [3]

$$(3) \quad W_{\min} = 1.7 * 1.0[mil] * 25.4 \left[\frac{um}{mil} \right] = 43.2[um]$$

$$W_{\max} = 2.5 * 1.0[mil] * 25.4 \left[\frac{um}{mil} \right] = 63.5[um]$$

For such a thumb rule it is always best to take the maximum value of the stitch width as it is the safer side. Still, this is only a good prediction and does not replace the need for an actual confirmation test for higher confidence levels. In case where a non standard¹ design (e.g. large Tip and/or small FA) it is best to take in to consideration the SWM results and add verify the results by actual wire bonding.

Another consideration that should be taken into account is the stitch pull degradation expected as the WD is reduced with the same capillary dimension. To fully understand the correlation between wire diameter and stitch pull it is best to refer to Mil-Std 883E 2011.7. The important understanding here should be that when a reduction of the WD is done, to reduce the stitch width, it is also recommended to consider a reduction in the stitch pull specification based on the known standards [3].

It is important to note at this stage that the model at hand was based on common designs with limited capillary geometry variations (CD, Tip, WD, FA range of 1.6-2.3 mil, 3.2-5.2mil, 0.55-1.2mil, 4-20deg respectively). Additional validation is needed for designs outside of these ranges.

Additionally, it is recommended to further study the influence of machine parameters on the second bond shape. Parameters such as X-Y table scrub and second bond approach are known to have influence on the shape which might have additional advantages when stitch width is too high.

Conclusions

¹ A standard capillary geometry received based on K&S recommendation for a given WD and Bond Bad Pitch (BPP)

1. WD is most influential when looking at the stitch width
2. When using a smaller wire diameter it is expected to receive a lower stitch pull
3. For standard designs max stitch width is in good correlation to $2.5 \cdot WD$
4. For non-standard designs it is possible to get a good stitch width prediction using the formulation SWM (actual verification is still needed per platform)

Acknowledgements

Special thanks to Sonnenreich, Beni for helping me gather the data in an efficient and prompt manner.

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