Solder Paste Deposits and the Precision of Aperture Sizes

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ABSTRACT
Many articles have been published indicating that 60 to 75% of all board assembly problems stem from solder paste printing. The important outcome from the printing process is to get the correct amount of solder deposited in the right place. A significant part of that solution is the stencil and its correctness depends on how well its manufacturing process is controlled using proper machines, materials, methods and manpower.

The quality of the stencil can be measured a number of ways: smoothness of the cut wall, material quality, thickness and thickness uniformity of the material, proper aperture location, proper aperture size. This report will show that significant variability exists in aperture size precision between various stencil manufacturing sources.

REASON FOR THE TEST
The most significant predictor of paste release from stencils is the area ratio (AR). This is the ratio of the aperture area over the aperture wall area and the larger the number, the higher the paste release percentage. Therefore if the aperture area is off by a certain percentage it will directly influence the area ratio and thereby the paste release from the stencil.

Historically the lower limit for the area ratio has been 0.66. Below that the paste deposit was expected to be insufficient.

TEST
For this test a dozen stencils were acquired, manufactured using different equipment and methods (various laser brands and types, various manufacturing processes as well as electro forming). These stencils were produced in normal production processes, some cut as sheets, others cut in a frame, without the vendors being aware of their purpose.

All stencils were scanned and measured using a large, high-resolution (12,000 dpi) flatbed scanner (LPKF ScanCheck) and the resulting measurements were analyzed. Prior to use the scanner was calibrated and had a maximum error of +/- 5 µm. All stencils were stored at room temperature.

The information obtained from the scanner included aperture location (X and Y coordinates), aperture type, area, position error and size error. Some debris is often still present in a few apertures of a new stencil and the machine does pick up this debris. It causes the area calculation of those apertures to be smaller than actual. With visual inspection of the data it is easy to recognize such apertures and to exclude them from the analysis.

By far the most commonly used stencil thickness these days is 125 um (5 mil), as are the stencils used in this test. The metal used is typically available with a +/-5 % or +/- 6.4 um (0.25 mil) thickness tolerance.

The stencil used in this test has an image size of about 325 x 500mm and contains about 21,000 apertures; about 14,000 of those are circles. In this analysis only circles are used. For both the smallest circles and the smallest rectangles the designed with an area ration (AR) greater than 0.7.

PRECISION OF APERTURES IN A LARGE STENCIL
The precision of the area of stencil apertures and the material thickness determine how close the paste volume will be with respect to the design goal. The dimensional precision of the aperture size depends on the stability, accuracy, use and maintenance regimen of the laser system. In the case of the electro formed stencil it depends on the exposure level of the film used, the exposure of the photo sensitive material on the mandrel and the control of the chemical process.

TEST RESULTS

The distributions of the areas of the apertures for each stencil are shown as a histogram in Figure 1. The vertical axis shows aperture quantities; the horizontal axis shows the percentage deviation of the aperture area. The best results can be recognized by narrower distributions (higher peaks) near zero percent.

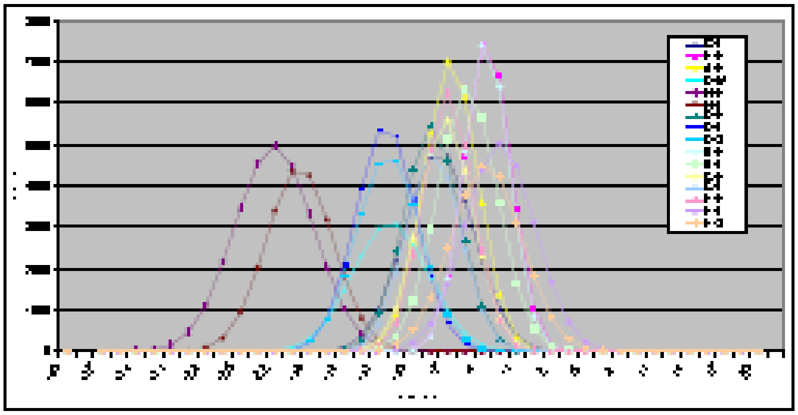

Fig 1: Distribution of aperture area for each stencil

The data acquired from the ScanCheck system was analyzed and a tolerance of +/- 10% was chosen for area limits. This allowed calculating Cp and Cpk for the various stencils and the results are shown in figures 2 and 3.

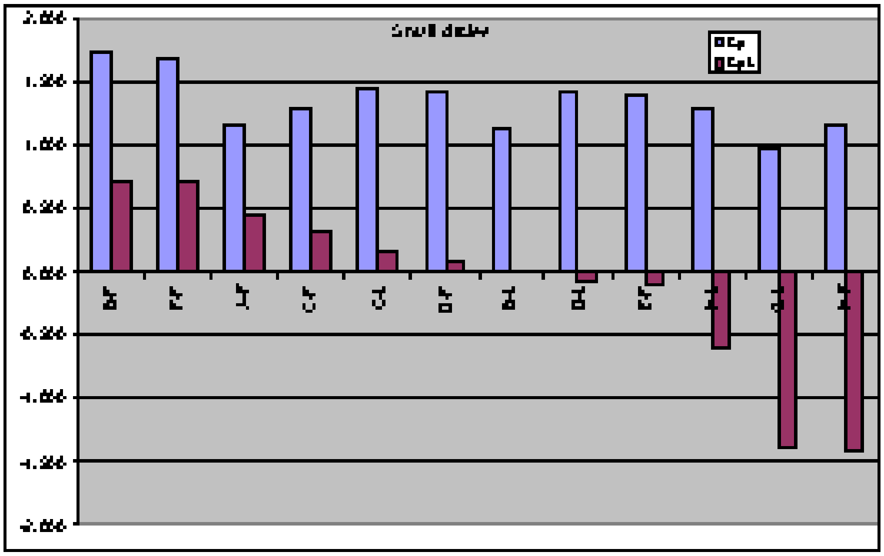

Fig 2: Distribution of Cp and width of aperture distribution size

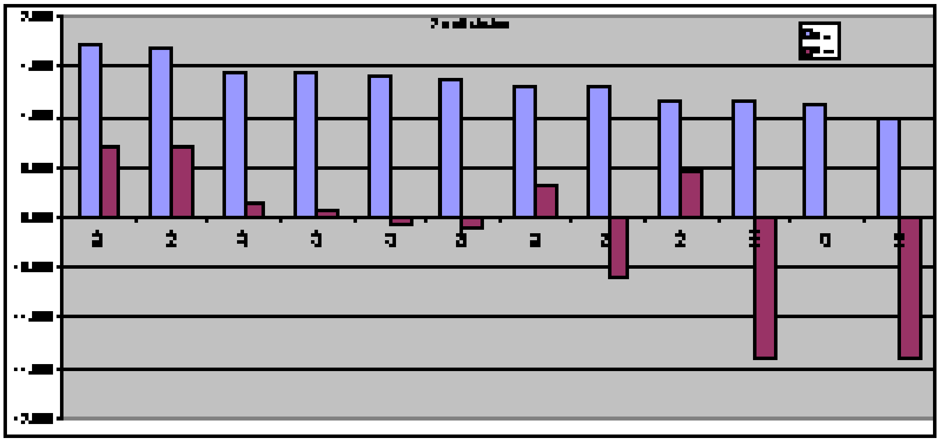

Fig 3: Distribution of Cpk and measured size distribution

Figure 2 shows the distribution of Cp from a high of 1.73 to a low of 0.98. This indicates that the width of the aperture size distribution of most stencils is close to or better than the width of the chosen spec limit, but the width distribution of the best performer is almost twice as good as that of the worst performer.

Figure 3 shows the distribution of Cpk. Cpk indicates how well the measured size distribution is actually within the spec range. Here we see that all stencils tended towards the smaller end of the spec range with several completely outside the low end.

IMPACT

From the data we can see that the Cpk of the worst stencil indicated that all its apertures were well outside the spec limits. The Process Mean for this stencil's aperture area was -24%.
The best stencil has a Cpk of 0.71, a Process Mean of -5% and with a Cp better than 1.7, very few of its apertures were outside the chosen area spec limit.

The smallest circular apertures in these stencils were 0.388 mm (15 mil), which for a stencil with a 125 µm (5 mil) thickness results in an area ratio (AR) of about 0.7. For the stencil with the worst process mean of -24% this means the AR is getting reduced to 0.53, which means that half the apertures have an AR of better than 0.53, but the other half is worse than 0.53. This is well below the historic limit of 0.66 and would result in poor print performance.

ROOT CAUSES

There are a number of root causes that are influencing the dimensional accuracy of an aperture in a solder paste stencil. The most significant source of avoidable inaccuracies in the industry is probably data processing. If the artwork file is processed without an exact consideration for the manufacturing method and knowledge of the laser system's performance this can lead to a significant impact on the Cpk.

Laser systems can operate with varying beam sizes, typically anywhere from 20 to 45 µm depending on laser technology, condition and maintenance. In many cases artwork files are processed with a "standard" beam size, but remember, the laser beam is equivalent to the bit in a milling machine. The size of the bit determines where the cutting path should be in order to cut the proper opening. As the stencil could end up being cut on any of a number of different machines with varying laser beam sizes it is necessary to know the beam size in order to get the correct aperture sizes. Lacking this information the result could be undersized apertures if calculating the cutting path using the large "standard" beam size but using a modern fiber-laser based system with typically a smaller laser beam. Similarly oversized apertures would result if cutting on an older lamp-pumped laser with typically a larger laser beam after calculating the cutting path expecting to use a much smaller beam. To avoid these pitfalls it is important for a manufacturer to frequently monitor and adjust for the actual beam sizes of the equipment in use.

Another cause of inaccuracies of aperture dimensions is the control of the position system. Such errors are typically showing much more variance in aperture size and this is mostly impacting the Cp of the aperture dimension accuracy. Laser cutting systems for instance, come in a wide variety of models and quality levels. The accuracy and stability of the positioning system can vary greatly.
Photochemical production methods such as e-form also require very tight process control to allow for higher Cp and Cpk values.

CONCLUSION

The above measurement results indicate that without knowing the manufacturing method used to produce the stencil the AR may vary between 0.7 and 0.53, possibly resulting in very poor print performance.
However based on paste release test results (Figure 4 and Ref 1) with the best choice of stencil manufacturing method and stencil material it may be possible to get acceptable paste deposits even with lower AR values.

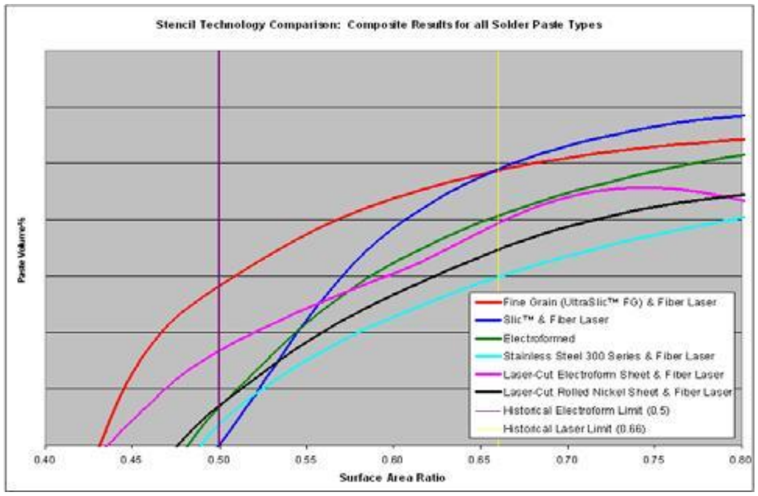

Fig 4: Paste release test results

In print tests represented by figure 4 the vertical yellow line indicates the historic AR limit. Using the intersection of this line with the commonly used stainless steel (300 series) line yields a given paste volume percentage. For the best material choice (fine grain stainless) that same percentage allows an AR of 0.52. This means that for the tests described above, with the worst aperture sizes it is necessary to choose the very best stencil material to even have a chance of obtaining acceptable paste release.

Now that we have learned that the size of the apertures can vary significantly due to manufacturing methods, previous reports (Figure 5 and Ref. 2) have shown that for the same reasons the aperture locations can vary greatly. For the same size and complexity of stencils location errors of up to 175 µm (7 mil) have been measured.

In short, it is necessary to know how a stencil is manufactured and the user needs to have to ability to verify the stencil quality, especially measuring aperture size and location as with the above test results and the referenced results it is clear that poor print results are not out of the question.

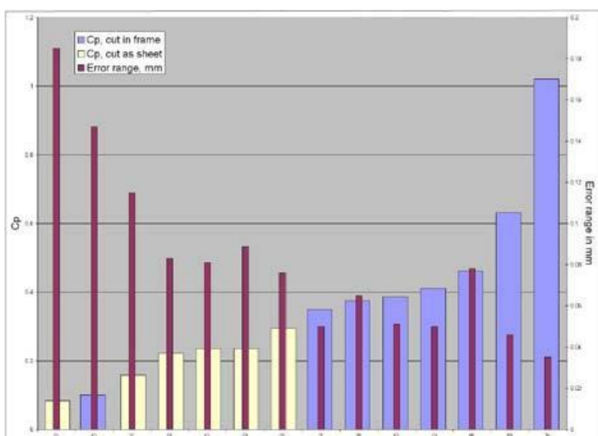

Fig 5: Variance of aperture size

References

[1] Robert F. Dervaes, Fine Line Stencil, Inc.; Jeff Poulos, Alternative Solutions, Inc.; and Scott Williams, Ed Fagan, Inc., "Conquering SMT stencil printing challenges with today's miniature components", Global SMT & Packaging, April 2009.

[2] Ahne Oosterhof, Eastwood Consulting, Hillsboro, OR, USA. ahne@oosterhof.com
Stephan Schmidt, LPKF Laser & Electronics, Tualatin, OR, USA. sschmidt@lpkfusa.com

"Solder Paste STENCIL Manufacturing Methods and Their Impact on Precision and Accuracy", SMTA Pan Pacific Conference, January 2011.

Introduction

Ahne Oosterhof

1956 Technical College in The Netherlands, EE degree
1960 Design engineer of video equipment at Philips, The Netherlands
1962 Manager of test department at Tektronix in The Netherlands
1966 Evaluation Engineer at Tektronix in Beaverton, OR.
1968 Design engineer, oscilloscopes
1971 Engineering manager, oscilloscopes, displays
1987 Engineering Manager + Manufacturing Engineering Manager, spectrum analyzers (complete SMT line).
1994 Market research to determine opportunity for laser-cut stencils.
1995 Founded A-Laser and delivered first stencil in August ’95.

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SOLDER PASTE DEPOSITS AND THE PRECISION OF APERTURE SIZES.

ABSTRACT:
Many articles have been published indicating that 60 to 75% of all board assembly problems stem from solder paste printing. The important outcome from the printing process is to get the ***correct amount of solder deposited in the right place***. A significant part of that solution is the stencil and its correctness depends on how well its manufacturing process is controlled using proper machines, materials, methods and manpower (the 4M rule!).
The quality of the stencil can be measured a number of ways: smoothness of the cut wall, material quality, thickness and thickness uniformity of the material, proper aperture location, proper aperture size. This report will show that significant variability exists in aperture size precision between various stencil manufacturing sources.

"Old" saying: I can make a bad stencil on any laser and a good stencil on some lasers.

History

- Silk screened stencils
  - Individual threads get in the way of paste transfer
- Chemically etched stencils
  - Double sided etching leaves ridge in aperture
- Electroformed stencils
  - High priced, more production steps, longer production time, lower accuracy
- Laser cut stencils (steel and polymer)
  - Getting better and better

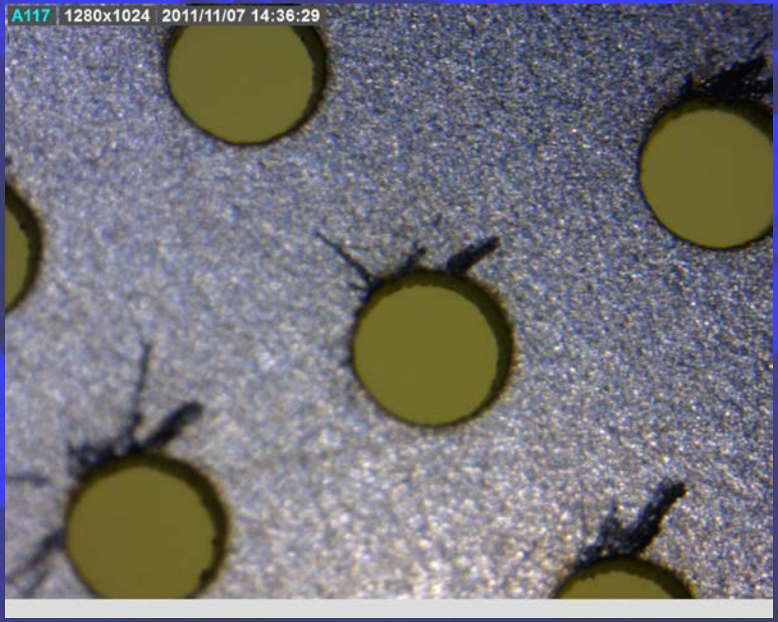
Laser cutting results: (machines)

- 1995: First lasers:
  - flashlamp pumped, low frequency
  - scalloped, like a postage stamp
  - almost smooth, like a form
- TODAY: Newest lasers:
  - diode pumped, high frequencies
  - smooth, like a knife

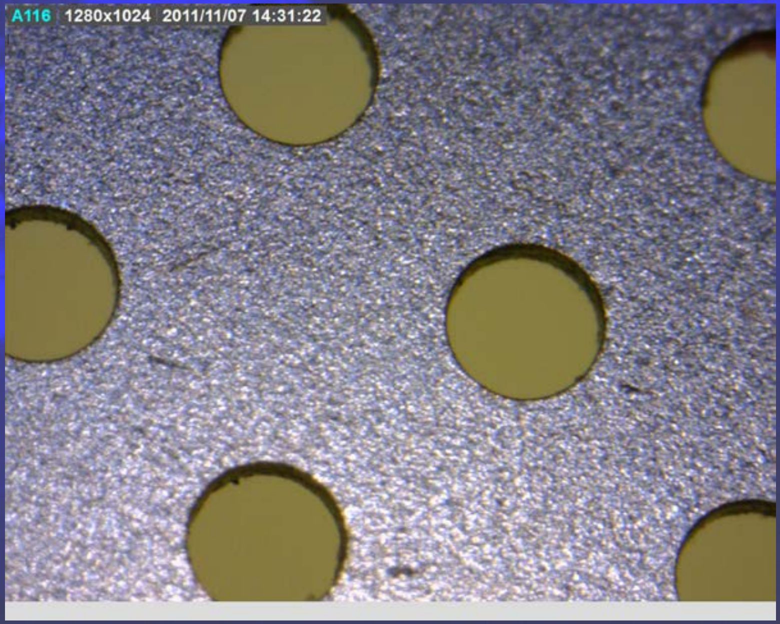
Laser cutting results: (machines)

- 1995
  - Leadscrew driven
  - Rotary encoders for position control
- TODAY:
  - Multiple linear motors
  - Glass scales for position control

MACHINE IMPROVEMENT RESULTS

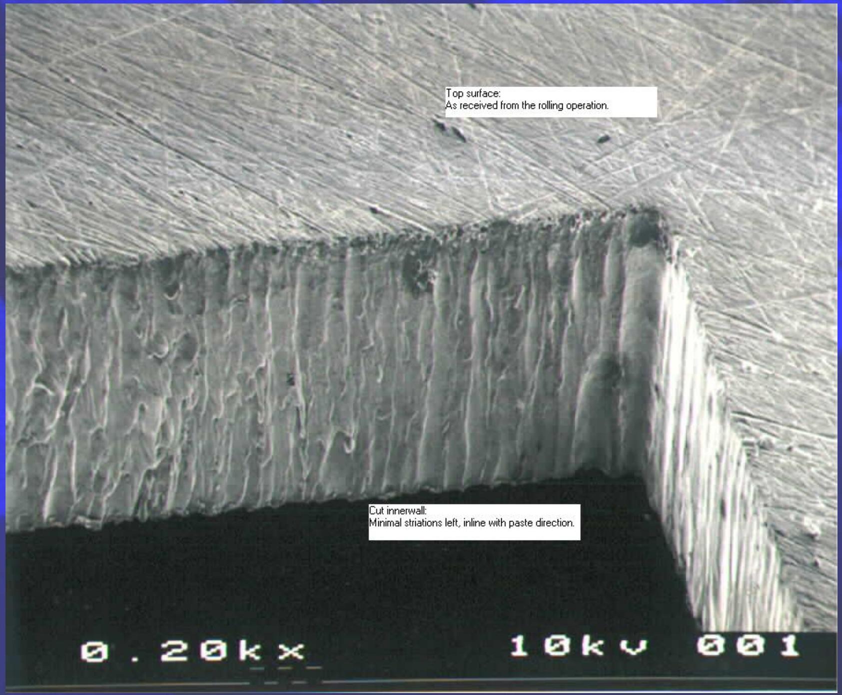


stencil cut on a legacy lamp-pumped laser

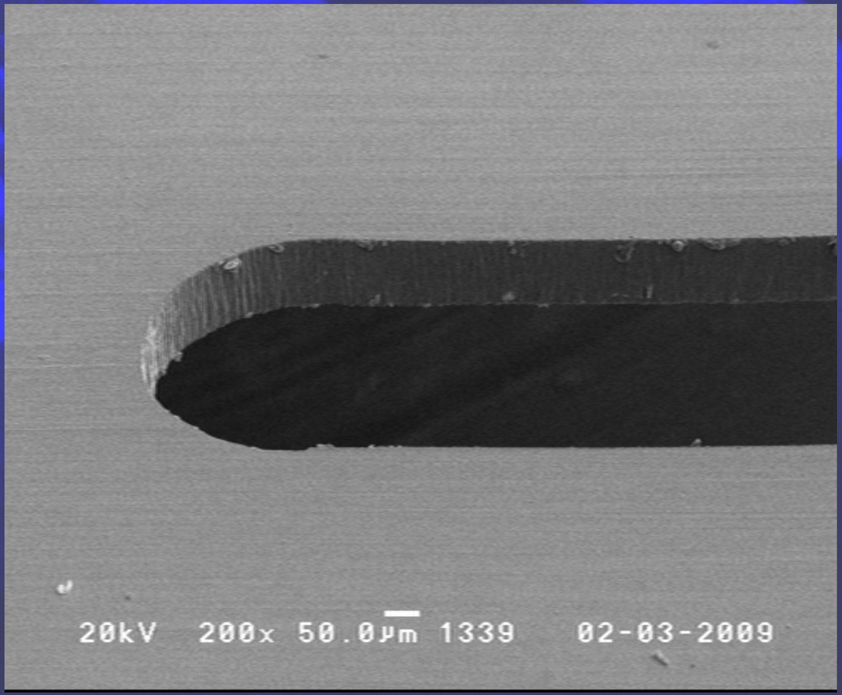


stencil cut on a diode pumped fiber laser

MACHINE IMPROVEMENT RESULTS



Flash lamp pumped laser.



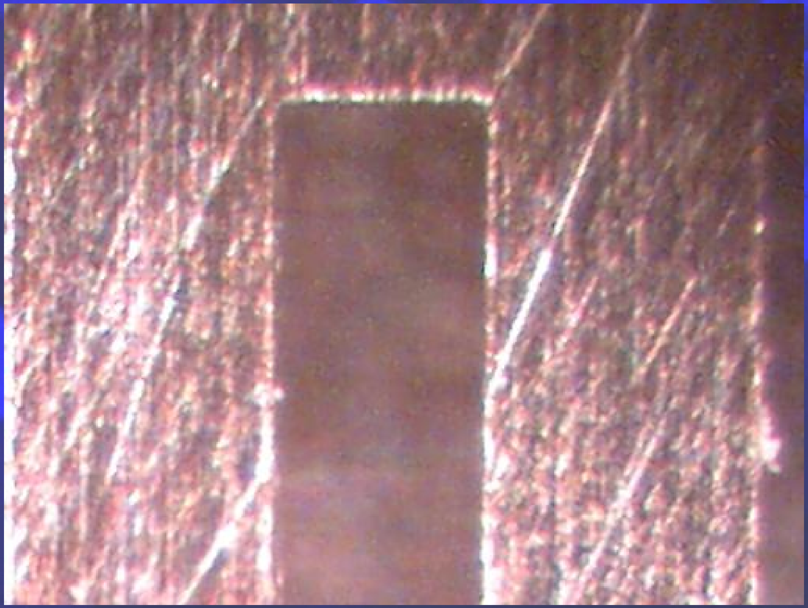
Diode pumped laser.

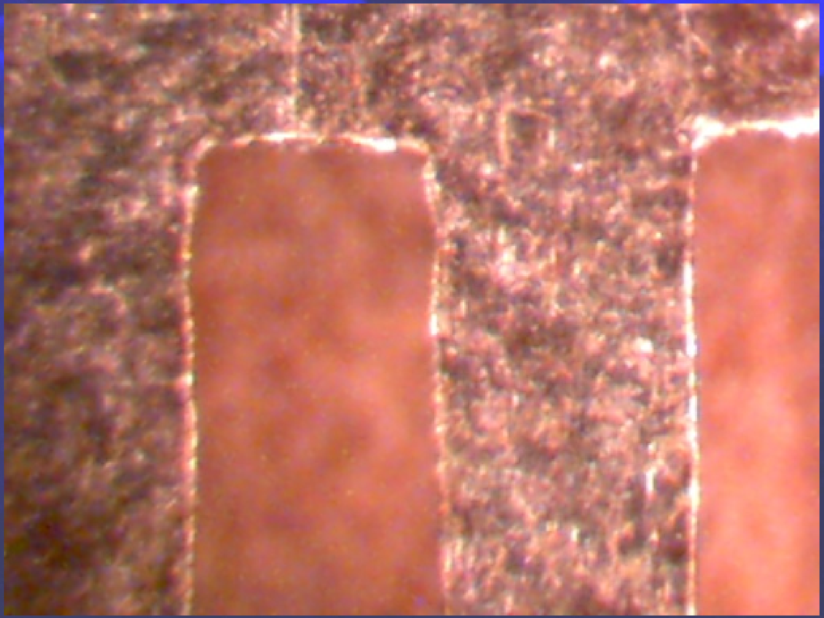
Performance impacts:

- Quality of the equipment used to manufacture the stencil: accuracy / precision
- Control over the process to fabricate the stencil: best materials / trained personnel / proper procedures.

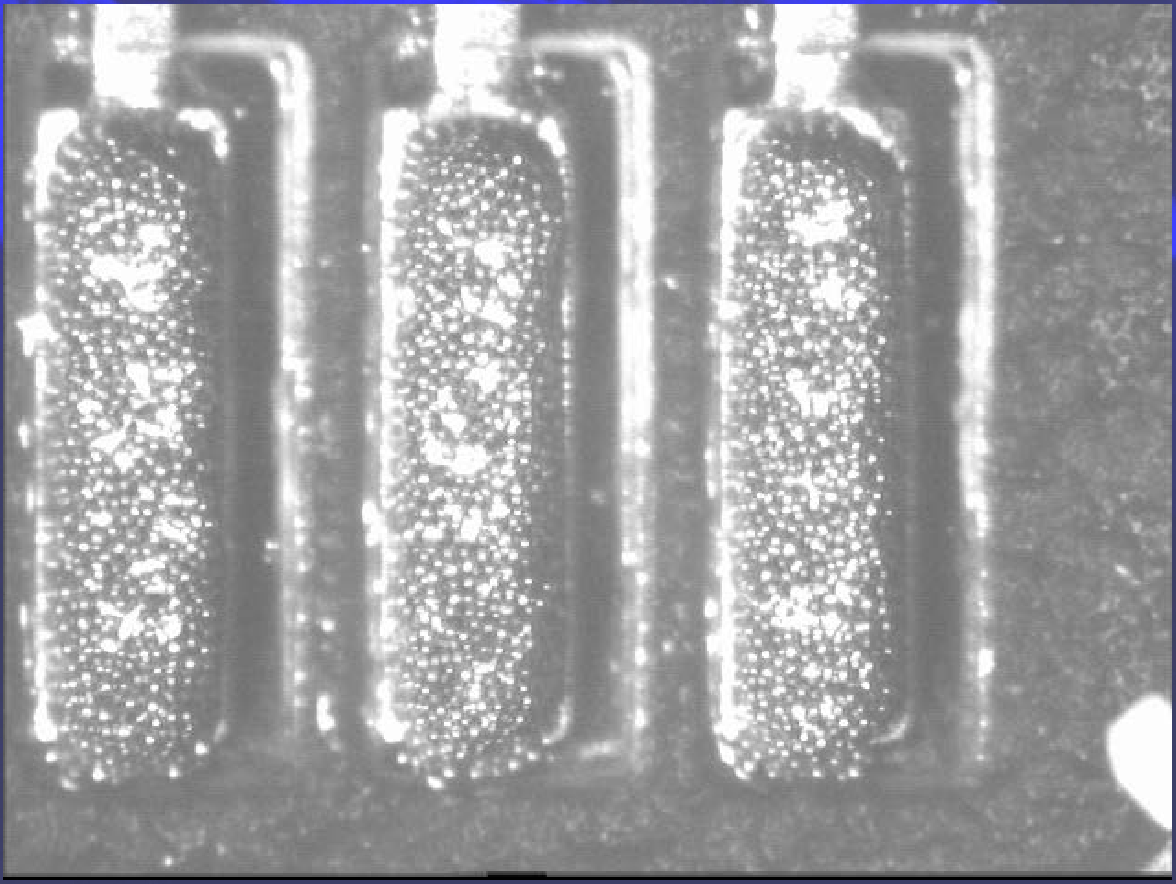
Laser Cutting

- Stability of laser beam
- Stability of movement system





Goal:
right amount of solder in the right place.



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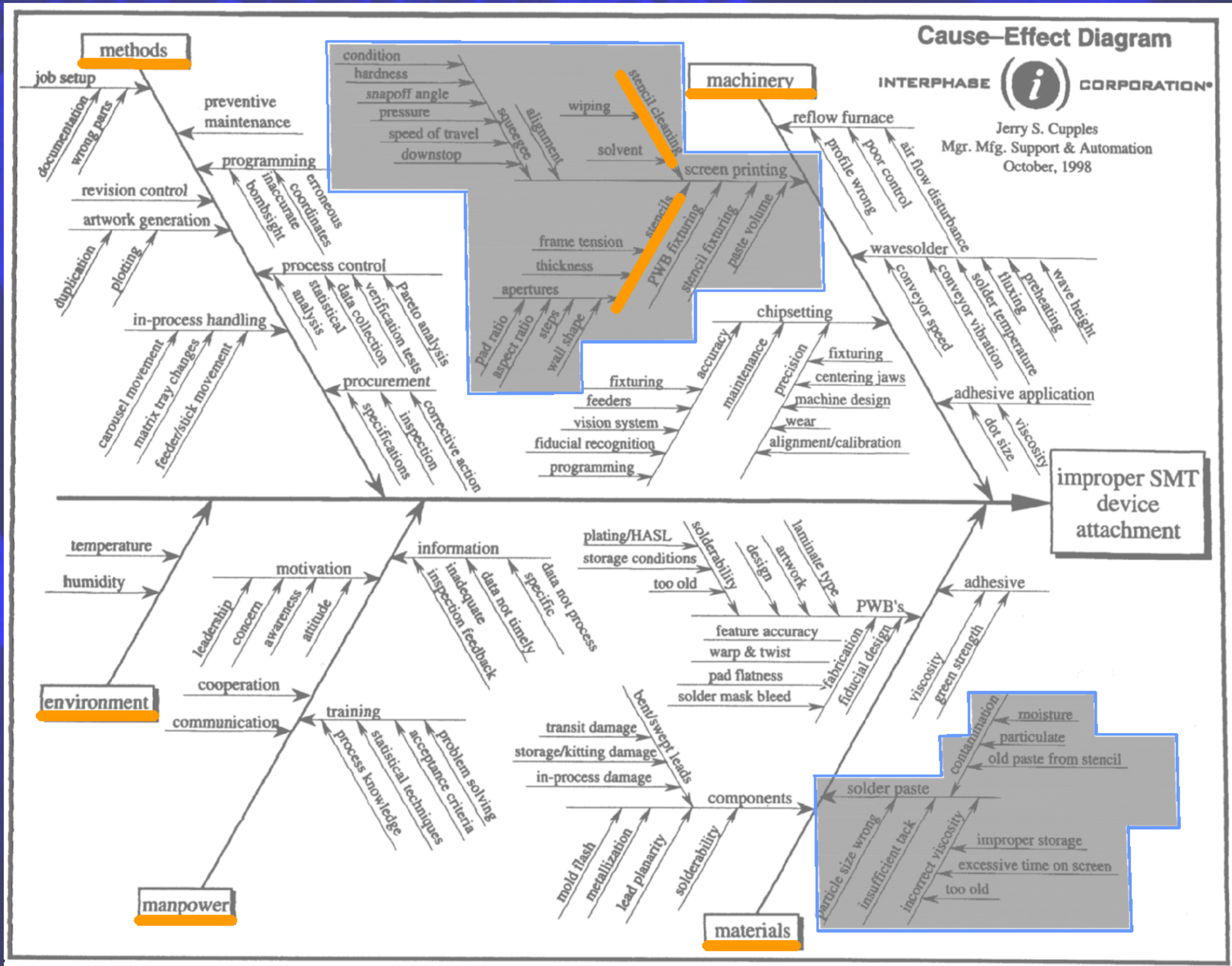


Laser cutting process

- Data processing
- Cut on laser system, in the frame

- Few steps, fewer problems, fast response

Electro forming process

- Data processing
- Produce film: projection accuracy / film stability
- Transfer image to a mandril
- Grow nickel (control bath chemistry and timing)
- Remove from mandril
- Mount in frame

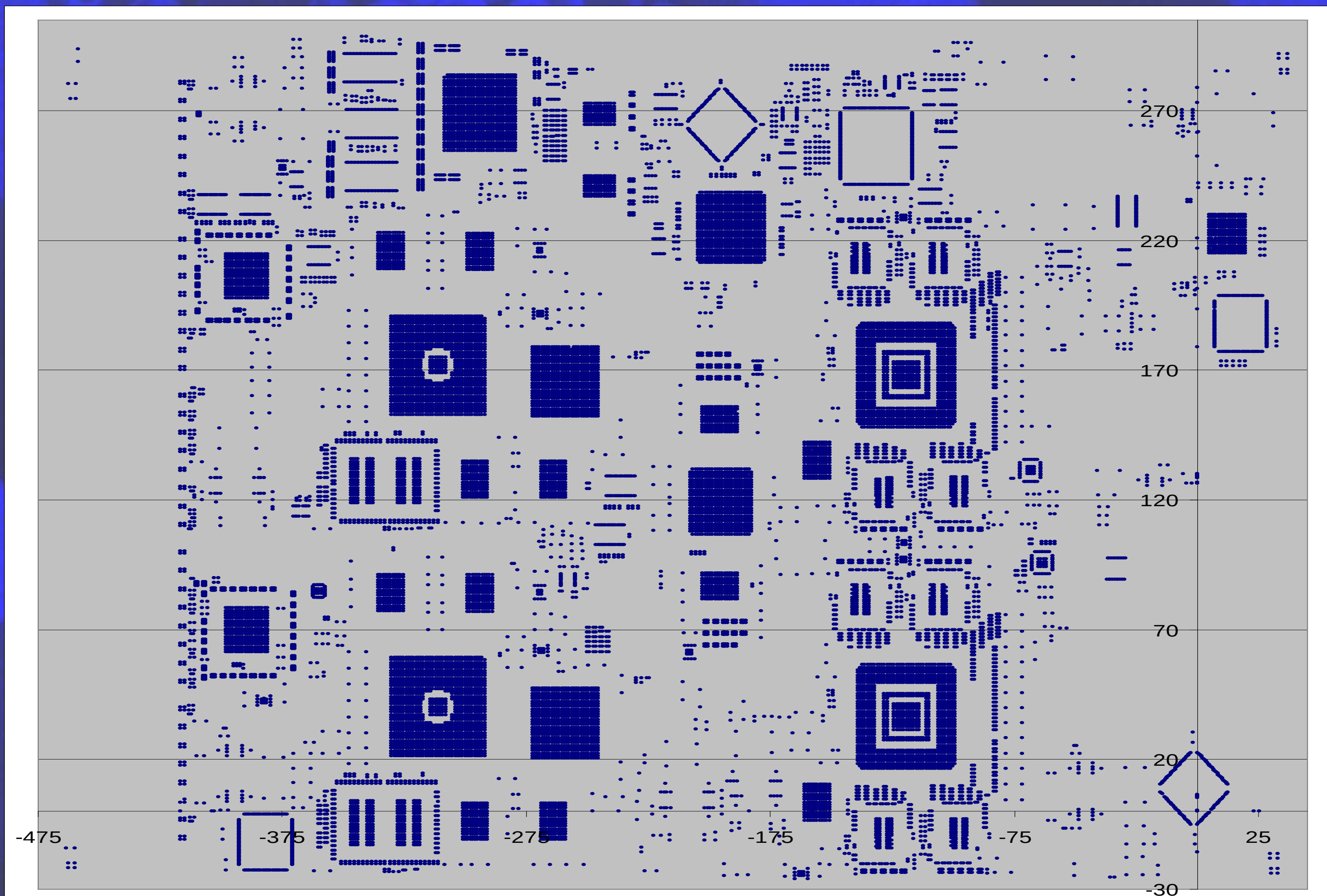
- More steps – more opportunities for errors

TEST

- Preparation:
  - 14 laser cut stencils
  - +1 electro-formed stencil
  - +1 stencil prepared and cut under known proper conditions on most modern laser
- Manufactured:
  - Different brand lasers
  - Different type lasers
  - Cut in the frame / cut as loose sheet
  - Electroformed stencil

Technology (AOI)

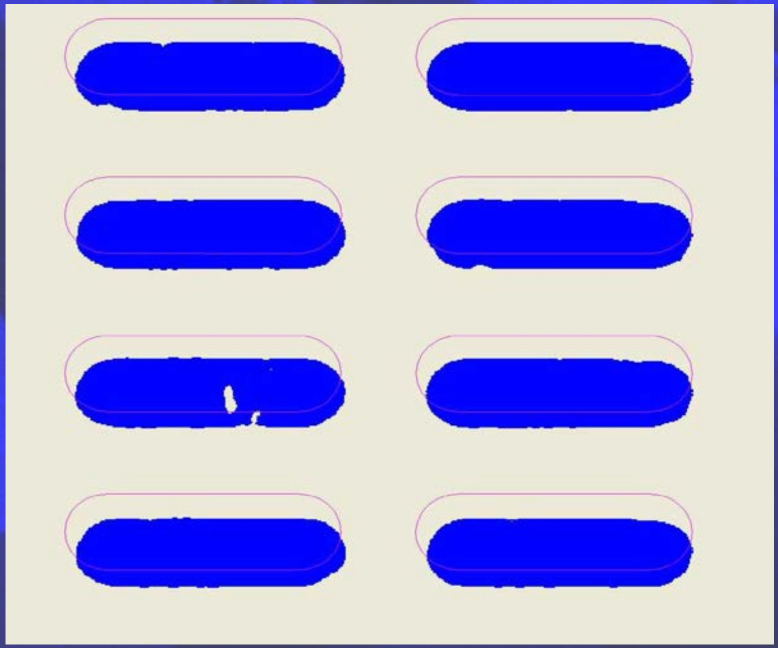
SCAN THE STENCILS

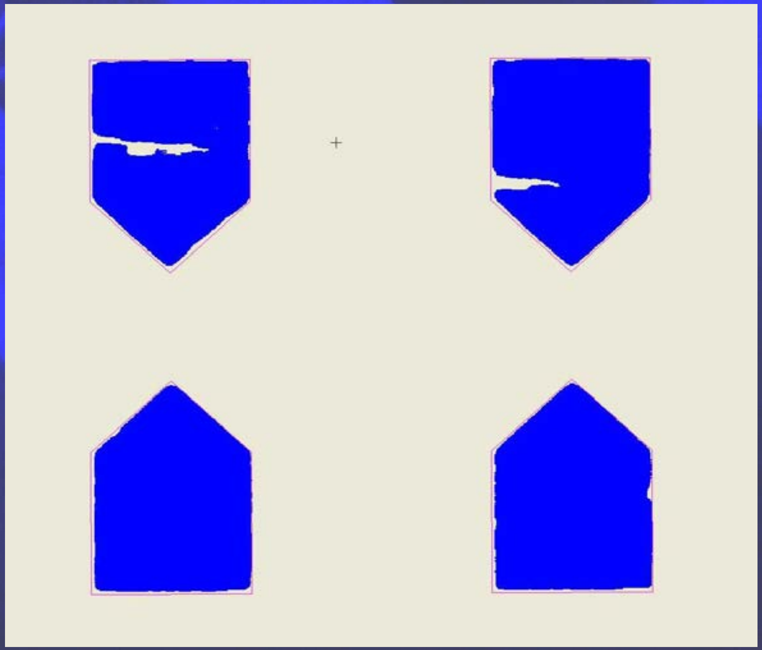


21,000 apertures, 350x500mm

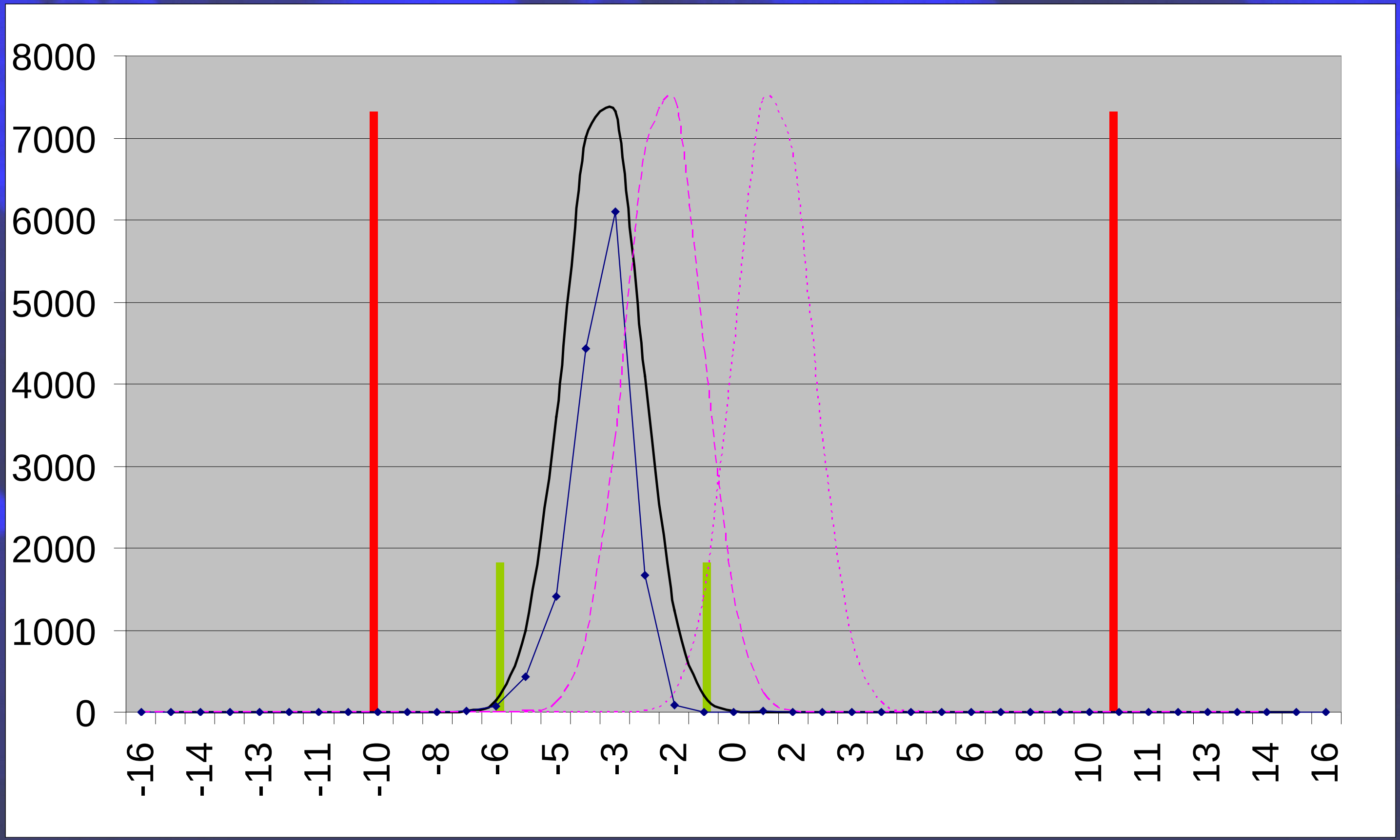
Verify

- Review the scans:



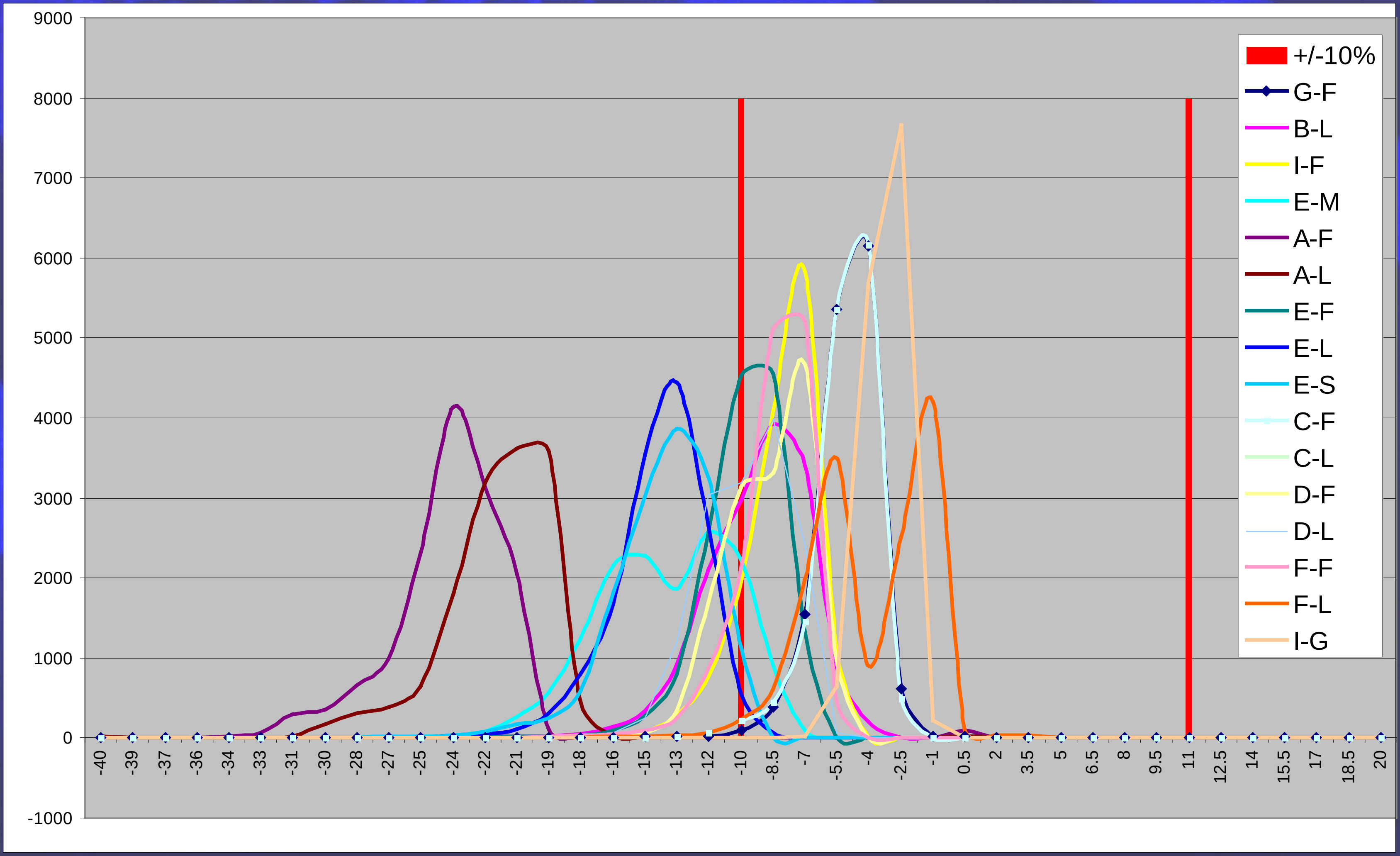


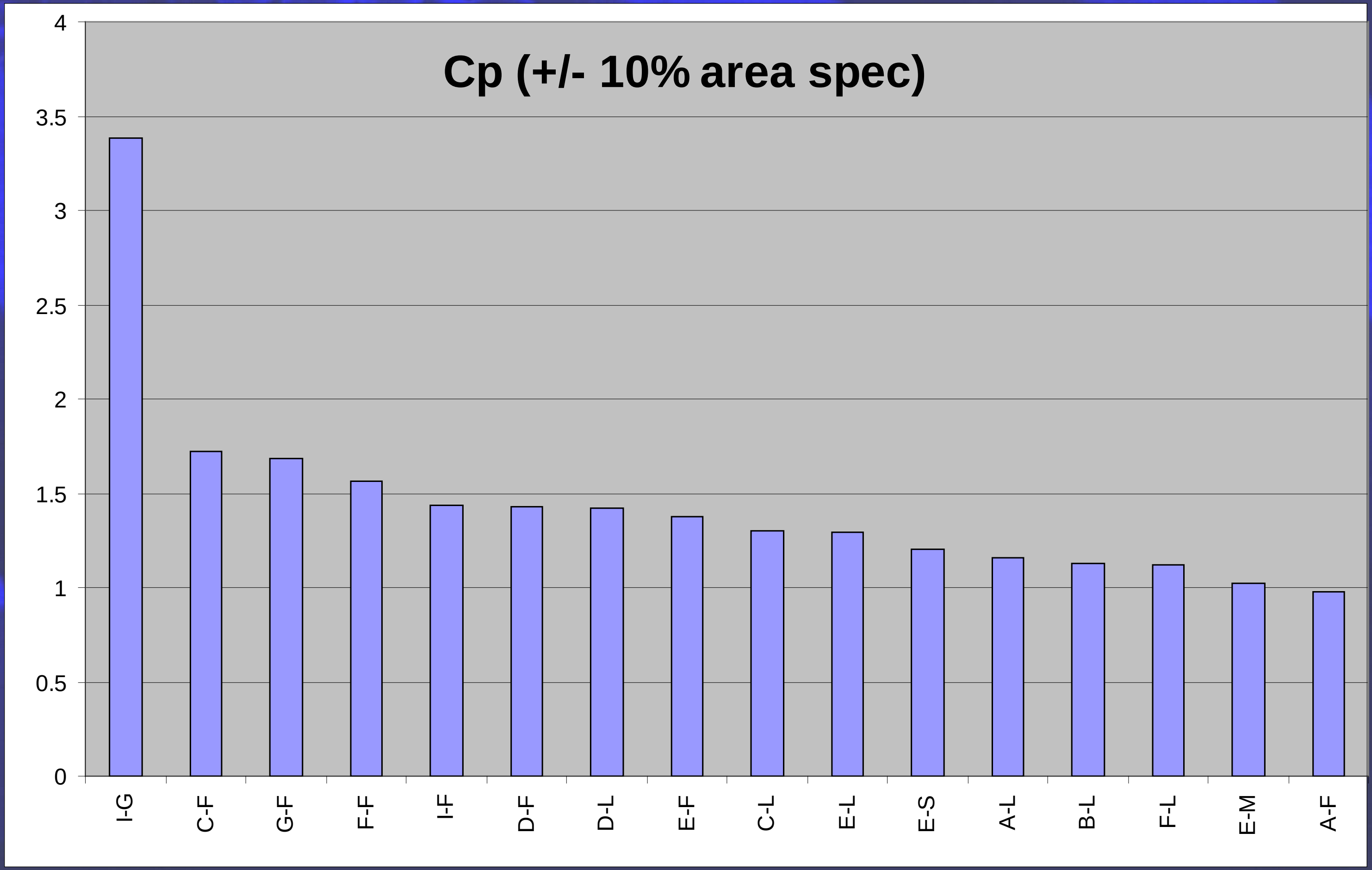
Analysis

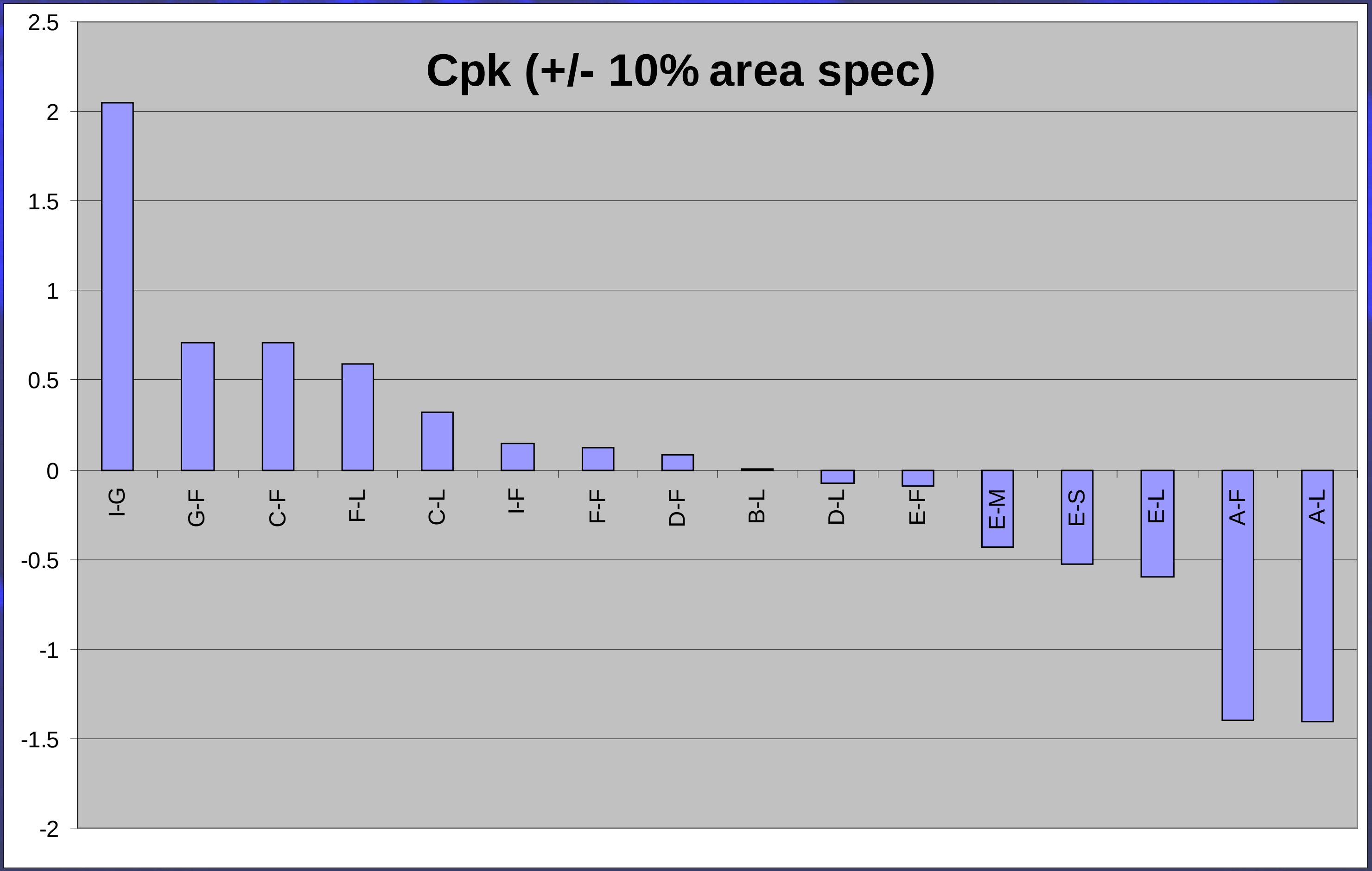


8000
7000
6000
5000
4000
3000
2000
1000
0
-16
-14
-13
-11
-10
-8
-6
-5
-3
-2
0
2
3
5
6
8
10
11
13
14
16

Distributions of aperture sizes



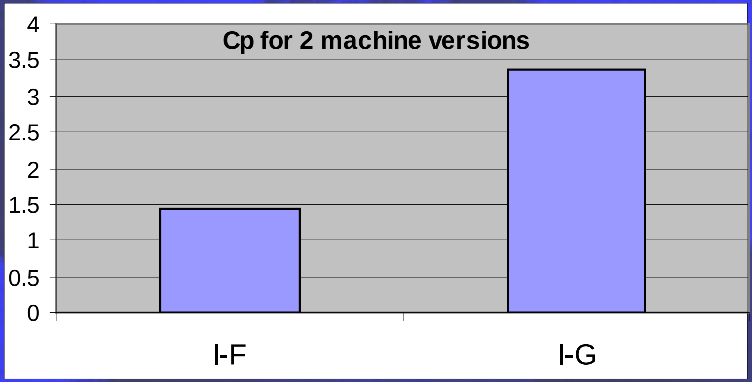

Cp (+/- 10% area spec)
4
3.5
3
2.5
2
1.5
1
0.5
0
I-G
C-F
G-F
F-F
I-F
D-F
D-L
E-F
C-L
E-L
E-S
A-L
B-L
F-L
E-M
A-F

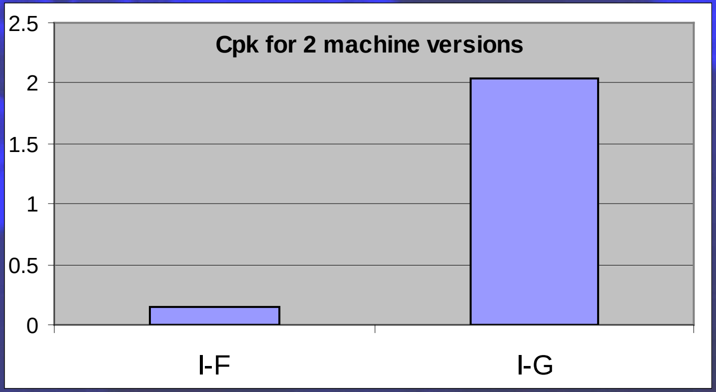


Cpk (+/- 10% area spec)
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
I-G
G-F
C-F
F-L
C-L
I-F
F-F
D-F
B-L
D-L
E-F
E-M
E-S
E-L
A-F
A-L

Old Technology

Technology Improvement





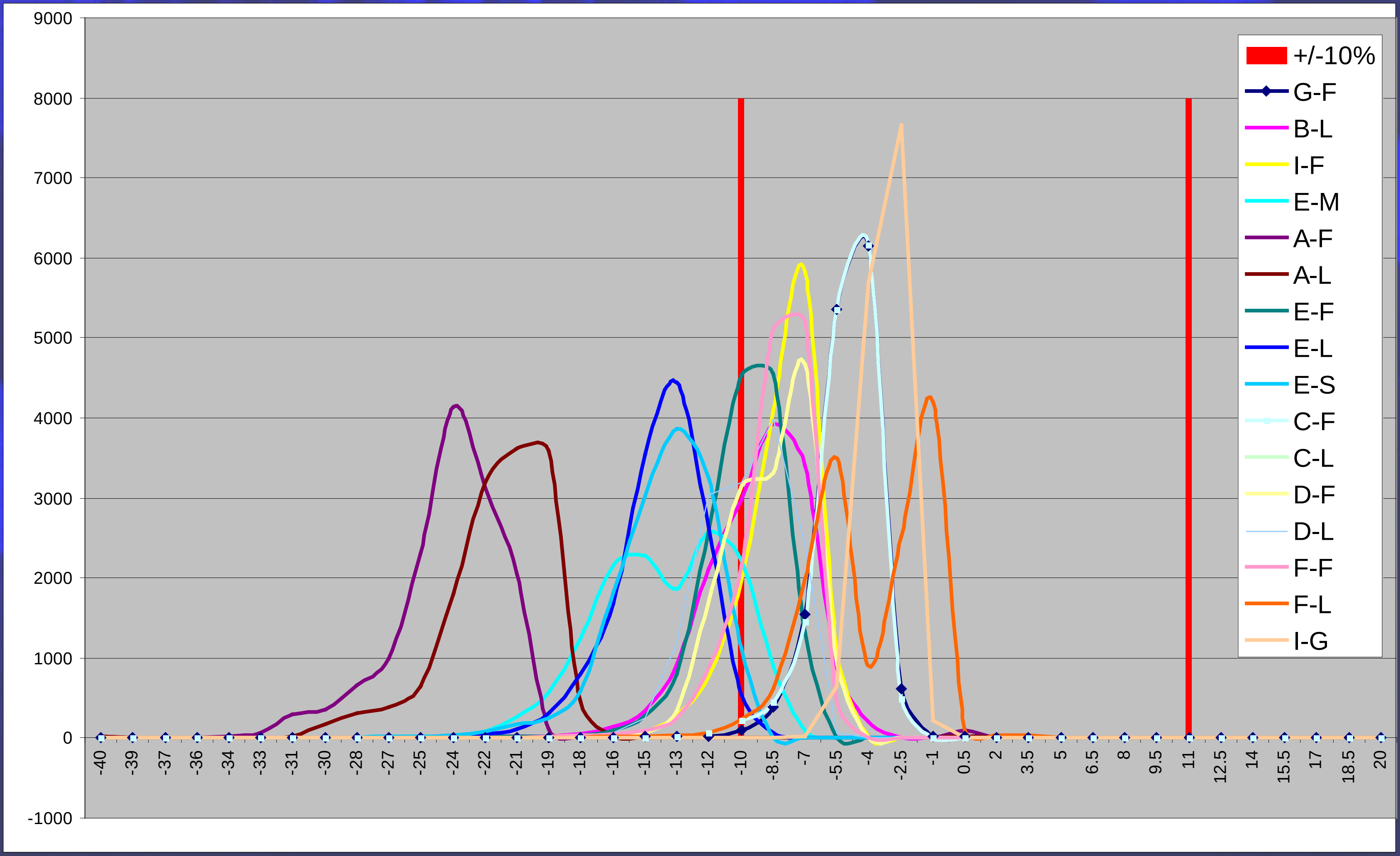
Modern Laser System

Production Process: Goal is 1500 / 500 / 50 / 0.5 ppm?

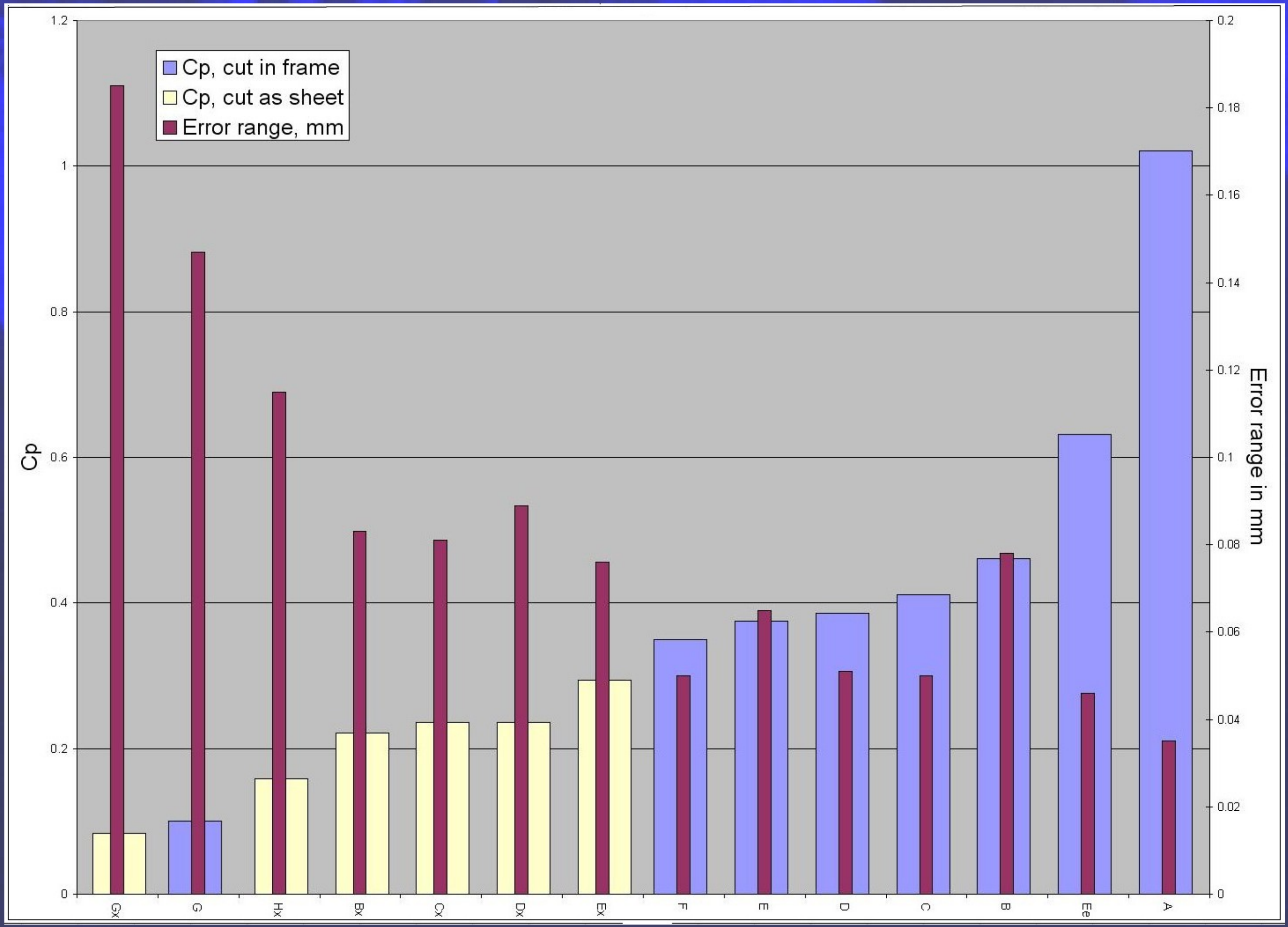
- World-class: <50 ppm
- Source of printing errors:
  - **accuracy of the stencil**
  - accuracy of the board
  - **accuracy of alignment, board to stencil**
  - **aperture quality**
  - **dimension of aperture vs stencil thickness (Area Ratio)**
  - **metal**
  - squeegee and printer operation
  - seal, stencil to board
  - solder paste

- Personal best experience: 7,000,000 opportunities / no errors !!
- Many users want a cheap and perfect stencil, which is of course not realistic.
  - But can you afford a cheap stencil?

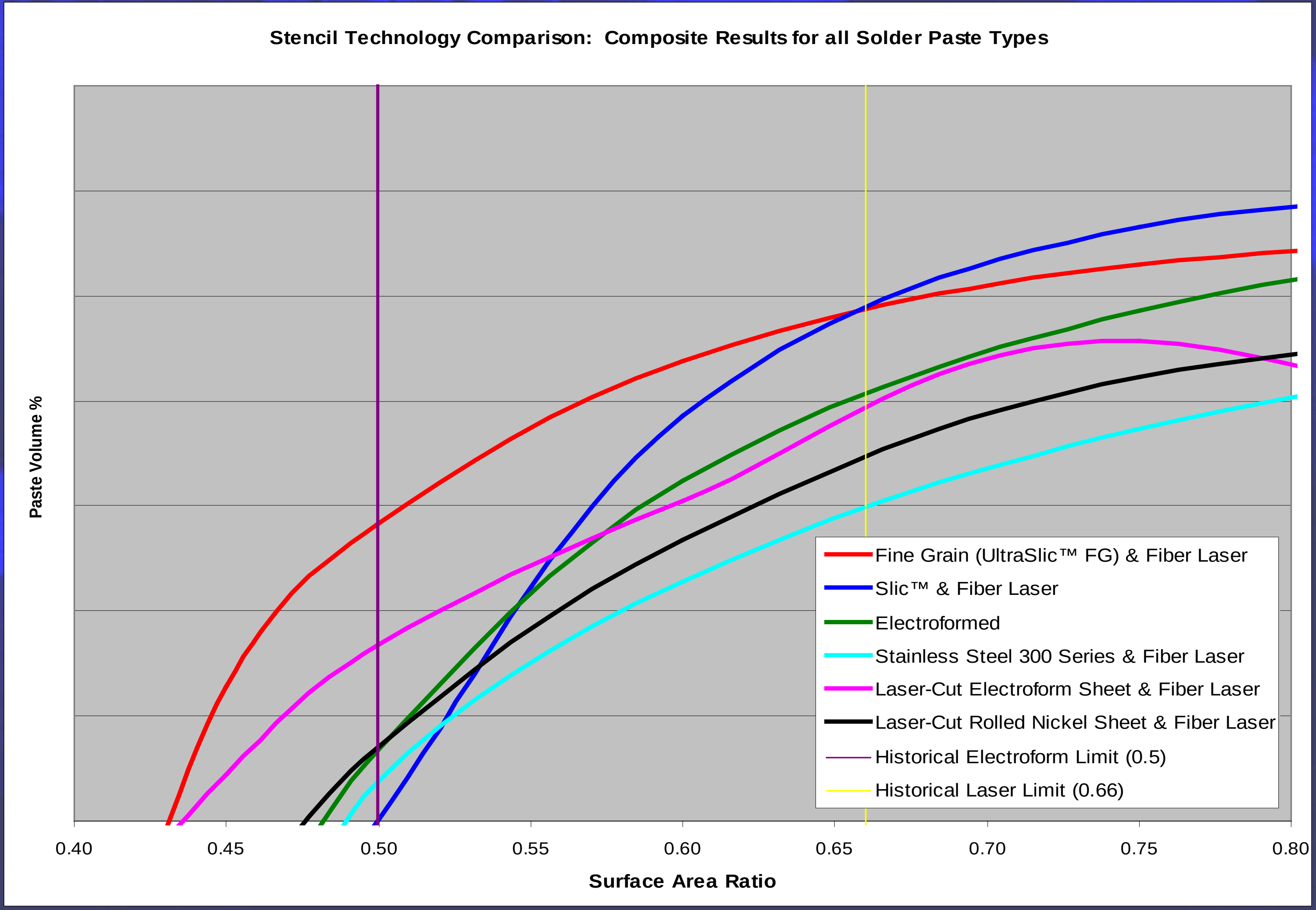
REVIEW: What can go wrong: aperture sizes



REVIEW: What can go wrong: Aperture location



REVIEW: What can go wrong: Paste release



REVIEW: What can go wrong: points to remember

- Additional printing errors can come from:
  - **Low mesh tension**:
    - When the mesh tension is low, the friction between the squeegee and the stencil may force the stencil away from the intended location.
  - **High squeegee pressure**:
    - High **squeegee** pressure means a high friction level which may force the stencil away from the intended location. (speed)
  - **Flimsy board support**:
    - If the board is not supported well, the downward squeegee pressure may deflect the board and present spaces between the stencil and the board allowing paste to leak off the pads.
  - **Board accuracy**:
    - If the locations of the pads on the board is not very precise, the stencil will be printing off the pads.
  - **Board quality:**
    - Planarity, warpage
  - **Printing process:**
    - 4 M

QUESTIONS?

- ---
- ---
- ---

My Question:

- What are your main problems with stencils?
  - ---
  - ---
- When do you call a stencil good?
  - ---
  - ---
- Do you need a measurement report?
  - ---
- What and how many print errors do you encounter and why do they occur?
  - ---

Conclusion re APERTURE SIZES:

- Original hypothesis: Aperture Precision (and positional accuracy) is a function of the manufacturing method.
- Cp: typically poorly built and/or maintained machines
- Cpk: typically poorly prepared data and/or maintained machines

- Conclusion: using the best laser and cutting in the frame yields the best results.

REMEMBER: A quality printing process assures that the proper amount of paste is deposited in the right place.