Ribbon Formation for Electrical Interconnection

Mentors: J. Michael Gray and Robert Shimpa

Kapil Ahuja, Yuan Dong, Huaiying Gu, Shiyuan Gu, Jon Van Laarhoven, and Jia Wei

Institute for Mathematics and its Applications
University of Minnesota, Twin Cities

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Outline

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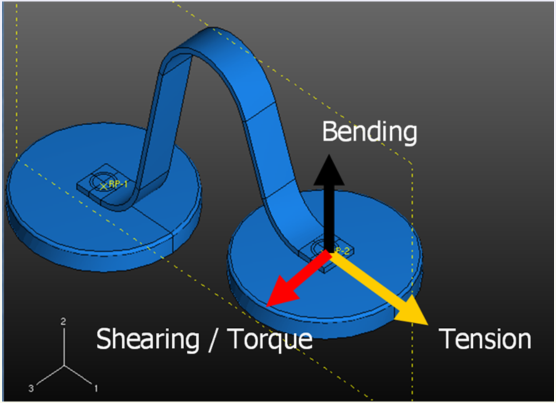
Four Steps in Ribbon Formation



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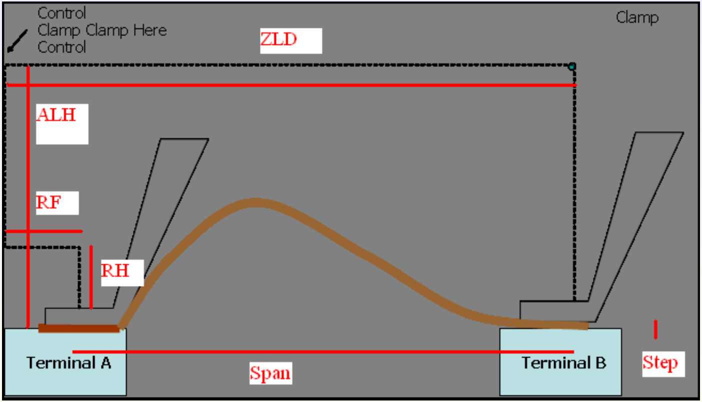
Objectives (with Focus on Looping)

1. Develop *empirical model* to predict loop shape based on machine motions and geometry.
2. Improved model by *incorporating material response* of the ribbon.
3. *Invert model* so that given loop shape and geometry, a set of machine parameters can be identified.
4. Develop a solver that can determine the *optimum loop shape* and the resulting machine motions given only the step & span.

Approach is to start with 1 and see how far we get!

Outline

Provided Input Params



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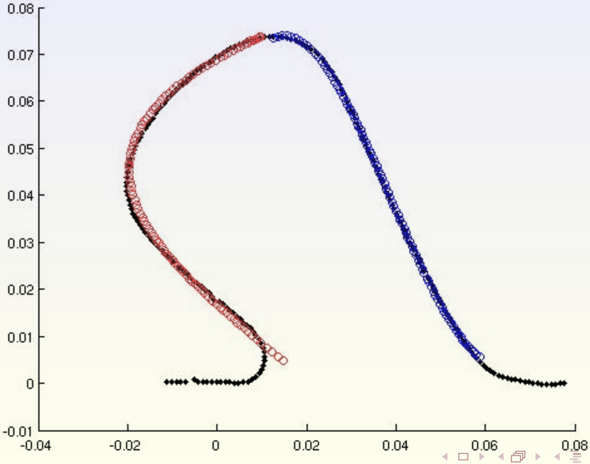
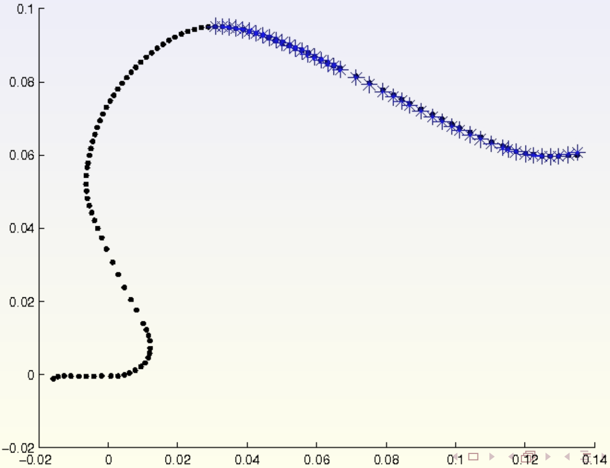
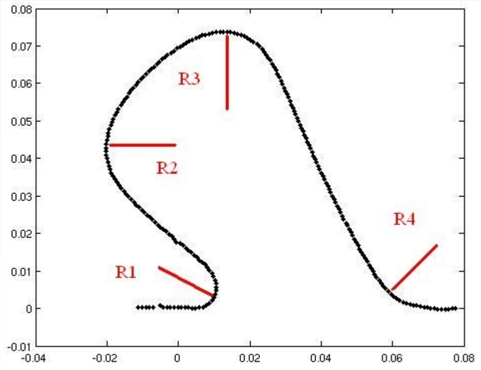
Output Params: Piecewise Cubics



Output Params: Piecewise Quintics



Output Params: Curvature



Engineering experience shows that the reliability has strong correlation with the $R1$, $R2$ and $R3$ . . ..

Output Params: Curvature, cont...

First Question: What is mathematical meaning of $R1$, $R2$,$R3\ldots$?

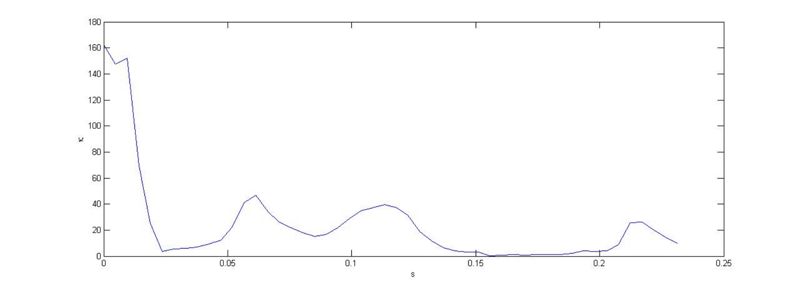
A natural thought: the local maximal of the curvature?

Splines can be used to calculate the curvature for the loop.

Curvature from splines

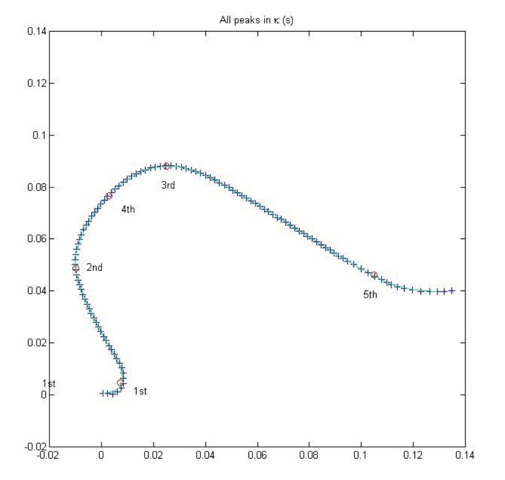
1. Resampling to 50 points. This step help us to smooth-out some local fluctuations.
2. Parameterizing by length and spline-interpolate the parameter equations:$r(s) = (x(s), y(s))$.
3. Compute the curvature by $\frac{r'(s) \times r''(s)}{\|r'(s)\|^3}$.
4. Pick up all the peaks by finding the 1st, 2th and 3th largest in magnitudge local curvature $\kappa(s)$.

Curvature from splines, cont...



We use the Boeing package *GeoGuck*. Thank you, Thomas Grandine and Team 4 members!

Curvature from splines, cont...



Curvature on a global level

BUT high curvature does not necessarily mean a bad loop, some good loops have higher local curvatures than bad loops.

Curvature, especially with our noisy data, is too local to capture global information. We solve this with a smoothing process.

Take the average of the curvature of a region of arc-length l:

$$\widetilde{\kappa(s)} = \frac{1}{2l} \int_{-l}^{l} \kappa(s+t)dt$$

Curvature on a global level, cont...

Results (for $l = 10\%$*total length) seem promising. We have 92 loop shapes with 60 “good" and 32 “bad", labeled by experienced engineers.

All the "‘good"’ loops have the $\widetilde{\kappa(s)}$’s *strictly less* than that of the bad loops!

Conclusion: $\widetilde{\kappa(s)}$ can indicate how reliable a loop is.

Curvature and optimal loop configurations

Second Question: How to make a reliable loop?

Related Question: What is the relationship between the $\widetilde{\kappa(s)}$ and the machine input parameter X?

We simplify X to $(R, ALH, step, span)$ where $R = \sqrt{RH^2 + RF^2}$ and then **Guess a Model!**

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Curvature and optimal loop configurations, cont...

We do RSM for some linear combination of X. $\widehat{\kappa_{max}} =$

$$45.5 + 144.2 * f_1 - 250.9 * f_2 - 891.0 * f_1 * f_2 - 1940.5 * f_1^2 - 456.6 * f_2^2$$

$f_1 =$
$0.0095 - 0.0029 * R - 0.0107 * ALH + 0.9992 * step - 0.0384 * span$
and $f_2 = -0.1913 + 0.0433 * R + 0.2125 * ALH + 0.0399 * step + 0.9754 * span$

The performance is not bad. 69 available loops. We use the first 60 loops for model fitting and last 9 loops for testing.

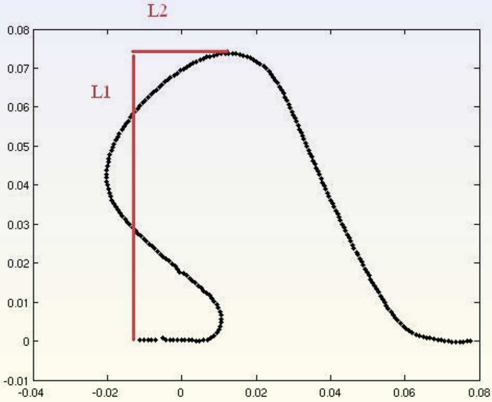
Fitting result: Fitting error is 10.7%.

Prediction: for 95% confident interval, 7 of 9 are predicted. The prediction preserve $<$ relationship.

What are f_1 and f_2? An approximation of a fundamental underlying physical factor or just artifacts of this experiment? Is this model believable?????

Output Params: Geometric Modeling

For a design engineer the most important aspect is the highest point of the loop (as shown in the figure below). Thus L1 and L2 form the output parameters.



Nonlinear Regression for the Geometric Model

We had three sets of experiments in which the input parameters were varied as follows:

$$\text{Exp 1: } \begin{pmatrix} Step \\ Span \end{pmatrix}, \text{ Exp 2: } \begin{pmatrix} Span \\ ALH \\ ZLD \\ RF \\ RH \end{pmatrix}, \text{ Exp 3: } \begin{pmatrix} Step \\ Span \\ ALH \\ RF \\ RH \end{pmatrix}$$

We plugged in the data from these models into MINITAB and used linear regression and DOE (Design of Experiments), which gave the three mapping functions.

Nonlinear Regression Continued ...

- The MAIN problem now was to combine the three models!.
- Matlab provides two types of nonlinear regression: Parametric Models and Regression Trees. Regression Trees gave a range of parameter values. How ever, the parametric model approach seem appropriate here.
- Pick all the terms from the three models (for all L1, L2, L individually), and combine it in one model. Then use this parametric model from Matlab to find the parameters (coefficients).
- The residuals obtained after using the model is small, and range of confidence intervals for the each parameter is also small.

Nonlinear Regression Continued ...

We used function “nlinfit” from Matlab. The function computes the least-squares parameter estimates for nonlinear models, and uses the Gauss-Newton at its core. An example of this fitting is as follows. Consider the three models:

- $L1 = 0.10 + 0.28 Step - 0.21 Span - 1.80 Step^2 + 0.84 Step * Span$
- $L1 = 0.10 - 1.04 Span + 0.01 ALH + 3.71 ALH * Span$
- $L1 = 0.06 + 0.44 Step - 0.30 Span - 0.13 ALH - 3.60 Span^2 + 4.76 ALH * Span$

Thus, the combined model is:
$L1 = A + B * Step + C * Span + D * ALH + D * Step^2 + E * Span^2 + F * ALH * Span$

Outline: Status of Current Tasks

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Optimum Loop Shape

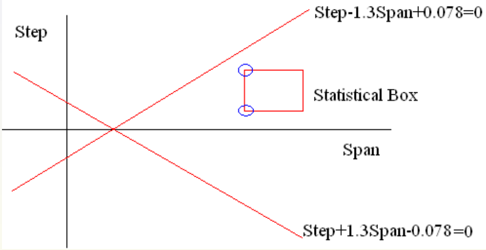
- The "Geometric model" gives an expression (L) and the"Shape model" (curvature model) gives an expression for max curvature (κ) in terms of the input parameters i.e. (*Step*, *Span*, *ALH*, *ZLD*, *RF*, *RH*).
- The main idea is find the optimal input parameters such that the curvature is *minimized* and the length is *maximized* (under a dozen design constraints). The objective function is made of the following parts:

$$y = w_1 \kappa + w_2 (1/L),$$

  where w_1 is the weight factor given to the curvature and w_2 is the weight factor given to the length (typical values could be 0.8 and 0.2 respectively).

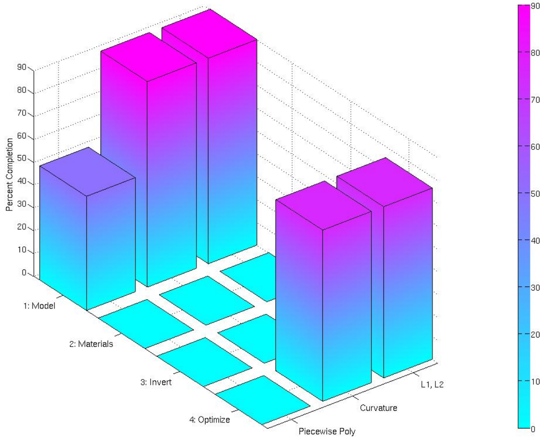
Optimum Loop Shape, Cont...

The optimization routine consists of two different parts. One in which the statistical box is fixed, and the other in which the this box is allowed to move in the global constraints enforced by the machine.



The challenging aspect in this part was writing a optimization routine that satisfied all the constraints.

Progress


Percent Completion
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1: Model
2: Materials
3: Invert
4: Optimize
Piecewise Poly
Curvature
L1, L2
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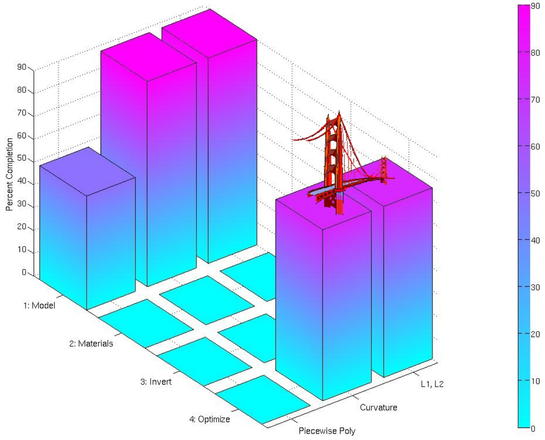
Progress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Questions?

Thank you!