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Professor Kirk's

2022 SATURATION CURVE SOLVER SUITE
SCS Version 10

Provided by

</div>

Introduction

Welcome to Saturation Curve Solver (SCS). These notes are intended to help readers to use these curve fitting templates. No prior knowledge is needed, only a basic familiarity with 'Excel'. It is assumed the user is already familiar with solving saturation curves. These templates were created with Microsoft Excel 365 and should work with versions dating back to 2007.

There are currently nine Excel templates in the 2021 Suite of Solvers: SCS1, SCS2, SCS3, SCS7, SCS9, SCS10, SCS12, SCS13, SCS15. These satisfy the needs of those performing shot peening and rotary-flap peening. The rotary-flap peening templates are specific to the magnetic correction method: AMS/3M or x0.77. These templates offer: simple curve generation when only 4 data points are used, the more accurate method when using 5+ data points, and the European/French method. Most users will require the use of only one or two of these templates to suit their needs.

The SCS template file names in this suite retain the legacy naming convention and provide a description of their function and release date. The file names are broken down in Figure 1 below.
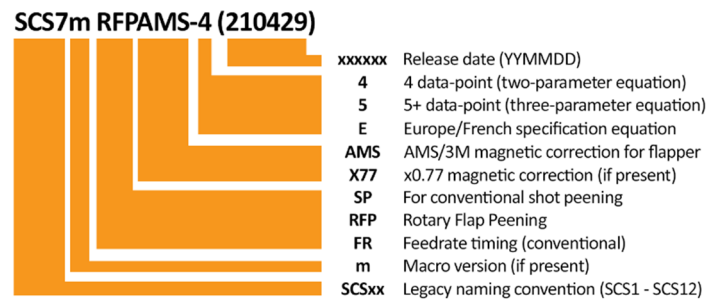

SCS7m RFPAMS-4 (210429)

xxxxxx	Release date (YYMMDD)
4	4 data-point (two-parameter equation)
5	5+ data-point (three-parameter equation)
E	Europe/French specification equation
AMS	AMS/3M magnetic correction for flapper
X77	x0.77 magnetic correction (if present)
SP	For conventional shot peening
RFP	Rotary Flap Peening
FR	Feedrate timing (conventional)
m	Macro version (if present)
SCSxx	Legacy naming convention (SCS1 - SCS12)

Figure 1

The 2021 Suite of Solvers currently does not include legacy templates SCS4-6, SCS8 & SCS11. These may be added later if demand warrants. New SCS13-15 templates have been added for time entered as a feedrate.

Note:

A user **must** have enough knowledge about saturation curve generation and solving to properly evaluate and accept the results of these curve solving templates.

Templates, not Spreadsheets

All the files are Excel "templates", with 'xltx' or 'xltm' file extensions. As templates, Excel will open them as a common "spreadsheet". This preserves the unaltered original file for future use. The file name of the newly opened file will remain the same but with a "1" (or sequential number) added to the end and will have the standard 'xlsx' extension. Excel will question if you want to save the file upon closing.

These templates are 'open source' where all the calculations may be viewed. For example, dragging aside the graph which appears on each Sheet 1 will reveal the method used to present a fitted curve. Highlighting any cell will show how the contents were obtained.

Each template has three sheets/tabs. The first is a "working sheet". The second displays a copy of the final curve with space for user-specified information. The third sheet is a set of 'test data' provided by the SAE sub-committee on saturation curve fitting.

Features

1. The template title. The first line of the title identifies which Saturation Curve Solver template it is. The second line has what equation is being used to generate the curve and the type of process. See "What Template to Use" in this guide for more information on the different templates.

2. Measured pre-bow values may be subtracted from arc height measurement after the strip has been peened. This process insures only the amount of bending due to the test strip being peened is used. The result after pre-bow subtraction is given as "Corrected Height". No subtraction is done if pre-bow cells are left blank.

3. Visual upper and lower intensity limits are shown on graph if entered.

4. A WARNING is displayed if the time at the saturation point (T) is less than the shortest peened strip time. This signals the result is considered a "Type-2" curve and peening specifications may require different intensity value than what is given.

5. An ERROR is displayed if the time at the saturation point is too large. Most specifications require at least one data point have a time equal to or greater than 2T (double the saturation time). Intensity and saturation times may be given, but they should only be used as a method to estimate how long the final test strip should be peened.

Figure 2

6. Program recommendations are given if a user either enters 5 or more data points into the 4 data point template or enters only 4 data points in a 5 data point template.

7. Rotary-Flap arc height correction is built into designated templates. Rotary-Flap peening requires arc heights to be adjusted due to the use of a magnetic test strip holder. One offered method of adjustment is outlined in SAE's AMS2590 specification, which is identical to the legacy 3M method. Another method offered is used by Boeing and Airbus specifications and simply adjusts to 77% of the measured value by multiplying it by 0.77. With both methods the measured arc height is entered, and the adjusted value is given as "Corrected Height". The "corrected Height" will also reflect the subtraction of pre-bow values, although pre-bow is rarely used with rotary-flap peening.

8. A large "RUN SOLVER" button runs a built-in macro to execute the common steps of solving the curve.

9. Curve evaluation. See "Data Set Evaluation" later in the document.

10. Verification target arc height. Enter in the desired verification time after the solver is run to display the target arc height expected for a test strip peened for that amount of time.
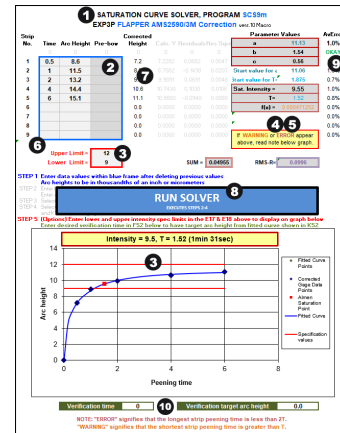
Which Template to Use

The first thing to consider before selecting which template to use is to know what type of work you are doing. If performing conventional shot peening, you have three template options: Using only four data-points for standard curve, using only four data-points for a European/French curve, and using five or more data-points to generate a standard curve. Below are the descriptions of each. See "The Curve Solver Equations" in this guide for more information about the equations.

Conventional Shot Peening Saturation Curves

SCS1 SP-4: Four Data-Point Standard Curve
This template uses the two-parameter standard equation (EXP2P) and recommended for curve generation if only four data-points are used. It should be noted that this equation creates a fitted curve that will forcibly flatten out. This may cause the solved curve not to fit perfectly along the path of the actual/corrected data-points. How far a fitted curve can be off is open to interpretation. To help you decide, the right side of the template shows the percentage of error between each actual/corrected arc height and the arc height on the fitted curve at that time value. An average error is also given. The template will indicate if an error of 5% or greater is calculated. The intent is to use only four data-points with this template, but up to eight data-points may be entered, however error percentages given only for the first four data-points.

If a better fitting curve is needed you may choose to use the SCS2 template. Using SCS1 or SCS2 is a matter of individual preference.

SCS2 SP-E: Four Data-Point European/French Curve
This template using the two-parameter European/French equation (2P) is **required** for curve generation per NFL 06-832. Only four data-points are used to determine intensity. As with the SCS1 template outlined above, the SCS2 template provides error percentages between actual/corrected arc heights and arc heights obtained from the fitted curve. The intent is to use only four data-points with this template, but up to eight data-points may be entered, however error percentages given only for the first four data-points.

This method of curve generation usually yields a better fit curve with less percentage of error. If NFL 06-832 is not required, the choice of which four data-point two-parameter template to use is up to you.

SCS3 SP-5: Five+ Data-Point Standard Curve
This template uses the three-parameter standard equation (EXP3P) and recommended for curve generation when five or more data-points are used. This equation creates a curve that fits all the data points very well, which can provide a very accurate intensity solution. To help evaluate the curve's fit, the right side of the template shows the percentage of error between each actual/corrected arc height and the arc height on the fitted curve at that time value. An average error is also given. The template will indicate if an error of 5% or greater is calculated.

It should be noted that using this equation with inconsistent process may lead to an ill-shaped curve and/or generate an unacceptable intensity solution.

SCS13 FR-4: Four Data-Point Standard Curve with Feedrate Timing
This "new for Version 10" template is identical to SCS1 (read above) with the exception of the peening "times" are in feedrate. Arc height will increase as the feedrate value decrease. The shortest amount of exposure to a blast stream is when movement across the Almen test strip is the fastest.

SCS15 FR-5: Five+ Data-Point Standard Curve with Feedrate Timing
This "new for Version 10" template is identical to SCS1 (read above) with the exception of the peening "times" are in feedrate. Arc height will increase as the feedrate value decrease. The shortest amount of exposure to a blast stream is when movement across the Almen test strip is the fastest.

Rotary Flap Peening Saturation Curves

SCS7 RFPAMS-4: Four Data-Point Standard Curve for AMS/3M Magnetic Holder Adjustment
This template functions like SCS1 (read above) except for arc heights being automatically adjusted for use of a magnetic strip holder per the SAE AMS2590 and 3M method. The AMS/3M arc height adjustment logic is shown below.

SCS9 RFPAMS-5: Five+ Data-Point Standard Curve for AMS/3M Magnetic Holder Adjustment
This template functions like SCS3 (read above) except for arc heights being automatically adjusted for use of a magnetic strip holder per the SAE AMS2590 and 3M method. The AMS/3M arc height adjustment logic is shown below.

AMS/3M Magnetic Adjustment

if y > 0.005" then x = 0.6 (y - 0.005") + 0.005"

y is the measured test strip arc height, and x is adjusted arc height used to generate a saturation curve

SCS10 RFPx77-4: Four Data-Point Standard Curve for x0.77 Magnetic Holder Adjustment
This template functions like SCS1 (read above) except for arc heights being automatically adjusted for use of a magnetic strip holder by multiplying the measured arc height values greater than five thousandths of an inch by 0.77. This method is primarily used in Boeing and Airbus applications.

SCS12 RFPx77-5: Five+ Data-Point Standard Curve for x0.77 Magnetic Holder Adjustment
This template functions like SCS1 (read above) except for arc heights being automatically adjusted for use of a magnetic strip holder by multiplying the measured arc height values greater than five thousandths of an inch by 0.77. This method is primarily used in Boeing and Airbus applications.

The Saturation Curve Solver Equations

These templates use three different equations to generate a fitted saturation curve. Two equations (EXP2P & EXP3P) are considered the standard and used by most of the shot peening world. The third is special equation used in European/French NFL 06-832 Specification (2PF).

EXP2P – Standard two-parameter equation intended to for use with only four data-points.

$$h = a(1- exp(-b*t)$$

h is the test strip arc height, t is the corresponding peening time and a and b are the two parameters

EXP3P – Standard three-parameter equation intended to for use with 5 or more data points.

$$h = a(1- exp(-b*t\char94c))$$

h is the test strip arc height, t is the corresponding peening time and a, b and c are the three parameters

2PF – European/French two-parameter equation required by NFL 06-832 with only four data-points used.

$$h = a*t/(b + t)$$

h is the test strip arc height, t is the corresponding peening time and a and b are the two parameters

All templates use the 'Method of Least Squares' to minimize the differences between data points and fitted equation points. A paper on the accuracy of Almen curve fitting appears in the Winter 2006 edition of The Shot Peener. That paper includes a discussion of the pros and cons of using different equations and different data set sizes.

Troubleshooting

Many "Shot Peeners" have been using these templates for curve generation and intensity solving for decades now! Tens of thousands of data sets have been analyzed with remarkably few problems. In hopes to help new users with issues that may arise, here are some of the more common problems that have surfaced:

Peening heights entered as "inch" rather than "thousandths of an inch".
Excel, although very powerful, is not a dedicated curve-fitting program. This means that it is not happy when it has to deal with the squares of very small numbers e.g., 0.0001 squared is only 0.0000001. The pragmatic solution is to always enter 'English' arc heights as thousandths of an inch and 'Metric' arc heights as micrometers. Hence, for example, 0.0001" is entered as 0.1, 0.0014" as 1.4, and so on. The routine use of 'thousandths/micrometers' has the added advantage that specification limits are generally quoted in those units.

This may also cause issue with time units. Adjusting all the time measurements by a factor for simplification will correct the issue.

'Solver' not Found
PC Users: Ensure there is a check-mark next to the "Solver Add-in" in the "Add-ins" dialog box.
Mac Users: Visit http://www.solver.com/welcome-mac-users-solver-now-included-excel-2011 for help.

Template Corruption
These spreadsheets are supplied as 'templates' (which have an .xltx or .xltm extension) so that changes made during use will not become embodied in the original file. Such changes, if accidental, could amount to corruption. It is strongly suggested to open the original template file from shotpeener.com / Electronics Inc. and save your results as a new Excel workbook to greatly reduce errors.

Data Set Evaluation
To identify curves that poorly fit a data set, these Version 10 templates evaluate the fit arc height value of each data point with that of the corrected arc height provided by the user. This is shown as a percentage of error. Error percentage below 5% will be labelled a "GOOD" fit, while any error 5% or larger is labelled a "POOR" fit. This evaluation is for informational purposes only and may help the user determine the quality of the data set, or which template to use. As example, using the SCS1 templates may result in a poor fitting curve, but the same data used in the SCS2 template will have a very good fit. Also see "Faulty Data Sets" below.

Faulty data sets
The individual data points making up a given set should satisfy two requirements: (1) be a reasonably good fit to one or other of the appropriate equations and (2) be properly distributed relative to the saturation point.

I recommend you also read Professor Kirk's Legacy Notes at the end of this guide.

Legacy Notes from Prior Versions of Professor Kirk's Templates

Equation preference/specification.
The two equations (EXP2P and 2PF) will yield very similar results for Saturation Intensity when applied to a four-point data set. This can be verified by comparing the Sheet 3 results using the two equations. The 2PF equation is the required equation when working to the French specification NF L 06-832 (December 1998). If 2PF is not specified, then it becomes a matter of individual preference. EXP2P is the simplest of these.

Perhaps the most important tenet of saturation curve fitting is that "Points should be fitted to a known curve". There is a seductive temptation to "Find a curve that best fits our points" – which is the wrong approach and must always be resisted. The correct approach is to select a particular program and let the computer find the best-fitting parameters of the corresponding equation.

Variability of Data Points
All measurements have an associated variability. The most familiar parameter is probably the 'standard deviation of a normally distributed variable'. A less familiar, but arguably more useful, variability parameter is the variance, which is simply the square of the standard deviation, σ. The advantage of using variance is that the total variability is simply the sum of the variability of each contributory factor. The total variability of Almen data point measurements, σ^2_T, is made up of the separate variabilities of the strips, measurements, and applied peening. Hence, we have that:

$$\sigma^2_T = \sigma^2_S + \sigma^2_M + \sigma^2$$

Where the S, M and AP subscripts refer to strip, measurement, and applied peening respectively. Almen strips are produced to very close tolerances so that the σ^2_S contribution will be very small.

The σ^2_M contribution depends upon the quality of the Almen gage and the operator's skill/assiduousness. It can be measured easily by carrying out repeat measurements on the same curved strip and calibration block. With careful attention to detail, σ^2_M will also be relatively small. The major factor contributing to variability will normally be σ^2_{AP}. During actual shot peening there will always be some variation of the parameters that affect strip deflection. Carrying out repeat measurements, for nominally identical peening parameters, can be used to monitor this variability.

The main reasons for the previous statements are to emphasize (a), we cannot expect to regularly produce data sets that will lie precisely on a given shape of equation, and (b) that we must be vigilant in our production of data sets.

The RMS-R value can be used as a direct measure of the variability of the data relative to the smooth equation curve. When a routine has been set up in each organization an average of the RMS-R values can be accumulated for comparison/control purposes. Note that the value will be greater, on average, the larger is the Almen intensity (simply because the numbers are larger).

Wrong choice of equation.
There is always a temptation to use an equation that contains too many parameters – on the grounds that "it looks better because it is a better fit". This temptation must be avoided! One user had problems trying to apply the three-exponent program to data sets comprising only four points. With only four points in a data set always use a two-parameter program.

If a given organization produces a mixture of four-point and five-or-more-point data sets. For the sake of consistency, it might then be preferable to use just a two-parameter equation. Five points allows one dubious data point to be omitted and still permits regression curve-fitting of a two-parameter equation.

Revisions:

03/31/2022 Rev C – Only changes to guide is year increment and this revision note. Corrected typo in instruction set. EXP3P Marco versions had un-needed line of code removed. Non-macro versions added to set.

01/18/2022 Rev B – Changed terminology from OKAY/BAD to GOOD/POOR in the templates. Added explanation of "Data Set Evaluation" to guide.

01/07/2022 Rev A – Added SCS2 macro templates to the Version 10 Suite. Added list of templated to guide. Added rotary flap peening curve solving to guide.