Speeds and Feeds Explorer

The Problem

Speed and feeds are at the centre of most machining tasks, and are just as important for machining wood, and other softer materials, as they are for machining metals. The theoretical underpinnings involved in machining processes are typically quite complex and are mostly resolved with the use of charts and tables provided by machine and/or cutter manufactures. For the woodworker this information is often limited, perhaps due to the wide variety of material cutting properties across the range of woods that are commonly used.

There are some well-known formulae (models) that can be used to describe the machining process, but these only partially describe the real material and cutter properties. For the available speeds and feeds tables there are often many assumptions that simplify the problem and, as a result, are often of limited value for practical use. As a result, it is the experience of the user through experiment and, perhaps, much trial and error that allows appropriate sets of feeds and speed values to be determined for known materials, cutter types and machine characteristics.

When I started working with my own CNC machine I spent some time looking for tools that might assist with setting speed and feed values, but this did not result in any really useful outcomes. It was largely through trial and error that I now feel reasonably confident that I can settle on a good combination of values for the range of woods and plastics that I work with. As always, some test cuts are often required to check the settings.

After some time I have now come back to the challenge, to see if I could better understand what the problem is and whether it might be possible to more effectively use/apply the known machining models. As a result I have come up with this proposal for a *Speeds and Feeds Explorer*., with a particular focus on CNC machining with wood. The purpose here is not just to identify a good speed and feed combination for a machining task, but rather to provide a tool that might better explain the machining model components, how they interact, and how they might be used to obtain an improved understanding of the problem. And, as a result, achieve that elusive goal of estimating good sets of feeds and speeds.

This is a work in progress.

The Model and Units

A simple model for machining can be summarised as follows:

Firstly, some definitions of terms (only metric units for the moment):

Term	Name	Definition	Metric Units
Cd	Cut depth	Depth of cut	mm
Ch	Chip load	The length of stock fed into the cutter per cutting tooth at each rotation.	mm/tooth
Cs	Cutting speed	Surface cutting speed, i.e. the speed at which the cutting edge passes over the material being machined	mm/min

Cw	Cut width	Width of cut	mm
Dc	Diameter	Diameter of cutter	mm
Fr	Feed rate	The velocity at which the cutter is forced into the stock	mm/min
Nf	Number of flutes	Number of cutting edges on the cutter	#
Ps	Power	Spindle power	Watts
Pu	Unit power	The power required to remove a unit volume of material per unit time.	Watts/mm^3/min
Se	Spindle Efficiency	Efficiency of power used by the spindle to remove material	Fraction
Sr	Speed	The rotational speed of the cutter	revs/min

Of these, the following parameters are primarily, but not only, properties of the material being cut:

Cutting Speed: This is the speed at which the cutting edge passes over the material to be cut. The optimum, or ideal, cutting speed for a given material will also depend on a number of cutting conditions, including life of the cutter, cooling/coolant conditions, cutter material (e.g. HSS or carbide), and so on. It is possible to find some tables of typical values from various cutter suppliers.

Chip Load: This is the thickness of the chip taken by each cutting edge as it is forced into the material being machined. The ideal values for chip load will depend on both material properties and, most probably, also on the cutter diameter and shape.

Unit Power: This is the power required to remove a unit volume of material in unit time. It depends largely on the material properties, but may also have some influences from the cutter type and shape.

These are the primary material properties that will determine the resulting feeds and speeds that will be best for a machining task.

The units adopted here might be considered a little arbitrary, but they have been chosen to eliminate the need to include conversion coefficients (e.g. mm to m, mins to secs) in the formulae described below.

There are three fundamental relationships that we need to consider:

Cutting Speed:

$$Sr = Cs / (\pi * Dc)$$

This relation defines the relationship between the cutting speed (Cs) and the cutter diameter (Dc) to compute the required spindle speed (Sr) as RPM.

The Metric Units are: $\text{min}^{-1} = \text{mm.min}^{-1}.\text{mm}^{-1}$

Chip Loads

Fr = Sr * Dc * Nf * Ch

This relation defines the relationship between the amount of material to be removed with each rotation of the cutter, defined as the chip load (Ch) factor, the feed rate (Fr), the cutter diameter (Cd), the number of flutes (Nf) and the spindle speed (Sr).

The Metric Units are: $\text{mm.min}^{-1} = \text{min}^{-1} . \text{mm} . \text{mm} . \text{mm}^{-1}$

Machine Power

Ps = Cw * Cd * Fr * Pu / Se

This relation estimates the power required by the spindle (Ps) based on the cut width (Cw), the cut depth (Cd), the feed rate (Fr), the unit power (Pu) and the efficiency of the spindle (Se).

The Metric Units are: $\text{W} = \text{mm} . \text{mm} . \text{mm} . \text{min}^{-1} . \text{W} . \text{mm}^{-3} . \text{min}$

These formulae offer a simplified machining model only. There are many more complexities that are necessary to fully define the real behaviour of the cutting tool.

Most Speeds and Feed calculators use these formulae, in various ways, to allow a user to enter some parameter values and compute some others (just like the calculator provided in CamBam). A number of Speeds and Feeds calculators can be found on the internet, mainly on sites of businesses that supply cutting tools, mainly for metallic materials, and often only in Imperial units.

While the formulae are the same for Metric and Imperial units, the values, and units, of the required materials property parameters are naturally different, so it is often quite difficult to get these parameters values in the correct and consistent units to suit a particular user's need.

The complexity in this task comes from the fact that the formulae are not independent of each other. That is, changing a value in one parameter in one formula, means that the other formula needs to be re-evaluated, and so generating a cycle of re-computations that are necessary to converge onto the required speed and feed values.

Implementation

In an attempt to provide a way of exploring these machining relationships, the *Speeds and Feeds Explorer* has been developed. In this application the three formula are presented "graphically" in an attempt to show their relationships and potential interactions. Here is the first attempt at a user interface:
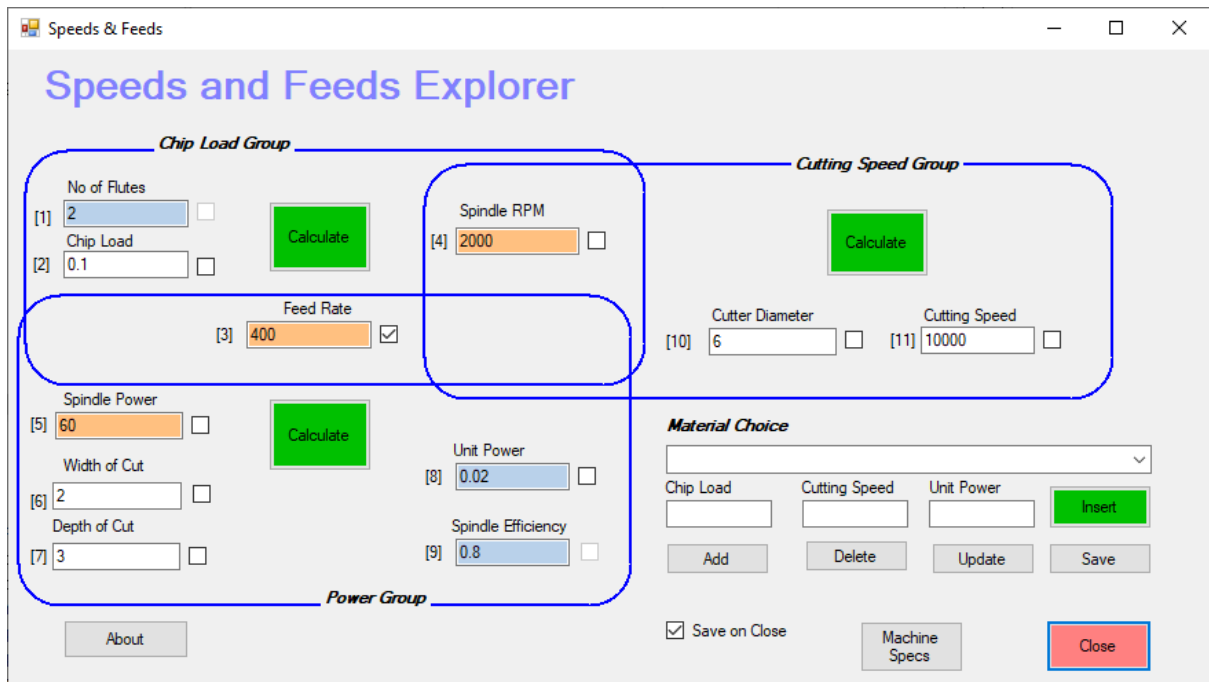
For the moment all the units are only metric, as described in the above table.

There are four sections in the UI:

- The Chip Load Group: that includes the chip load calculation formula.
- The Cutting Speed Group: that includes the cutting speed formula.
- The Power Group: that includes the machine power formula.
- The Material Choice section: that allows the use to select from a list of predefined materials. This list is created by the user and saved to a local XML file to be loaded on start up.

Within each Group (as defined by the rectangular boxes) we have:

- A text box where the value of each relevent parameter is inserted/presented.
- A checkbox for each parameter that, when selected, indicates which parameter is to be computed, with a result based on the set values of the other parameters in the same group. Only one parameter in each Group can be selected at any one time. Selecting one checkbox in a Group will automatically deselect the others.
- A "Calculate" button that will evaluate the formula to produce the computed value for the selected parameter, based on the specified values of the other parameters in that group.

As a result we can clearly see those parameters that belong to each group, and which ones are shared with other groups.

The Material Choice section consists of:

- A combobox to select one of the available material/cutting options included in the associated list (contained in XML file located in the same folder as the start-up EXE file).
- Each material choice includes:
  - A material name: to be used to describe the material/cutting options. For the moment this field should be used to describe the material and perhaps some of the other cutting options (e.g. "Wood/Jarrah/SUC6" might be used to define the

material category, specific type, cutter type and diameter). There is no special significance to the syntax (user defined).

- o The items in the combo will be presented in the combo in alphabetical order, on restarting the program.
- o If no list is found on start-up, an empty list is created.
- o The data items for each material item are
  - ▪ The chip load value
  - ▪ The cutting speed value
  - ▪ The unit power value.
- An "Add" button is used to add a new material choice to the list, using the values currently defined.
- A "Delete" button is used to remove the currently selected choice from the list.
- An "Update" button is used to update the currently selected item with the new values as entered in the text fields.
- A "Save" button is used to save the current parameter values and materials list to the local XML data file. The Save operation will normally automatically happen on "Close" unless the "Save On Close" checkbox is cleared.
- The "Insert" button that will take the currently displayed values for chip load, cutting speed and unit power and insert them into the matching text boxes in the Group sections.

The "Machine Specs" button launches this dialog:
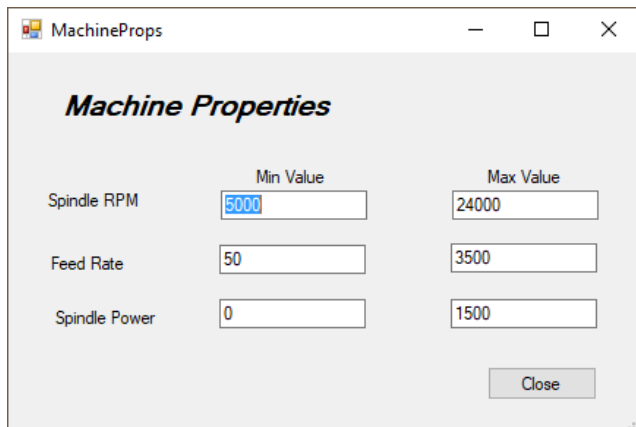
The machine Properties dialog allows the user to enter a range of "reasonable" values (as a min and max value) for the spindle speed, feed rate and spindle power. This data is saved in the local XML data file when the program is closed.

Installation

- Unpack the zip file into a suitable location
- There will be two files:
  - o SFCalc App.exe – the executable
  - o SFData.xml – a sample data file. This file must remain in the same folder as the executable.
- Launch the program by double clicking on the executable.

Instructions for Use

Given the interactions between the formulae there are many different ways of using the program. Some examples are given in the next section. In general, however:

- If you know the values of all but one of the parameters in a Group, then these values should be entered, the checkbox next to the missing parameter should be "Checked" then the "Calculate" button in that Group used to compute the missing value.
- Some parameter checkboxes are currently disabled, where it is not useful to calculate their values.
- If a computed parameter is also included in another Group, then this may suggest the need to re-calculate that Group also. If the same parameter is re-computed in the other group then its value may change. In this case it may be necessary to review/correct one or more of the pre-set parameter values, and compute again, perhaps repeating until a suitable consistency is found.
- By setting known feeds and speed values, it is also possible to compute the implied property values (not all). This may be useful where you which to check an actual value against a limiting value.
- When one of the parameters (Feed Rate, Spindle RPM or Spindle Power) is calculated and the resulting value is outside the user definedn min -> max range for that parameter then the text box is highlighted (as a red colour) to flag a possible inconsistency.

When the program launches the list of available materials as well as the default parameter values are loaded from a local XML file. The material choices are then available in the Material Choice combo. When one of these items is selected the associated parameter values are displayed in the text fields under the combo. If you wish to insert these values into the Groups, then use the "Insert" button.

The items in the Material Choices can be deleted, updated, and new items added.

When the program is closed, the current parameter settings and material choice data is always saved, unless the "Save on Close" checkbox is cleared.

Some Sample Data

The following table contains some sample material properties that I have managed to extract from various on-line sources, and with some liberal interpretations. These values are not definitive in any way as no allowance for cutter types, materials, shapes etc. have been factored in.

Material	Chip Load (mm/tooth) for Cutter Diameter (mm)				Cutting Surface Speed (mm.min^{-1})	Unit Power (W.mm^{-3}.min)
	3	6	10	12		
Hardwood	0.10	0.25	0.4	0.5	230,000	0.0040
Softwood	0.12	0.3	0.45	0.55	280,000	0.0020
MDF	0.15	0.35	0.55	0.65	280,000	0.0020

Material						
Soft Plastic	0.15	0.25	0.25	0.3	10,000	0.0010
Hard Plastic	0.18	0.27	0.27	0.35	15,000	0.0050
Aluminium	0.07	0.1	0.15	0.22	150,000	0.0200
Mild Steel	0.1				20,000	0.0350
Hard Steel	0.1				20,000	0.0400
Brass	0.1				120,000	0.0200

Readers are invited to offer specific (corrected!) examples from their own experience that might provide better starting points.

Cautions

The following cautions should be observed:

- Currently there are no error checks for invalid data values and typos.
- The sample material properties provided may be of limited accuracy.
- Care is required to choose the parameter values in the correct units.

Example Uses and Strategies

Here are some examples of use:

Example 1: Estimating feed rate and spindle speed given the properties of the material to be machined.

1. Choose material from Material Choice combo (e.g. "Wood/MDF")
2. Click "Insert" button to transfer chip load, cutting speed and unit power to matching Group fields.
3. Set cutter diameter (say 6.0) in field the Cutter Diameter field.
4. Select spindle speed checkbox
5. Click "Calculate" button in cutting speed group – spindle speed estimated to be 14854 RPM
6. Select Feed rate checkbox in Chip Load Group.
7. Click "Calculate" button in Chip Load Group – feed rate estimated to be 1040.
8. It might seem that this is rather slow, so enter 1500.
9. Select spindle RPM checkbox
10. Click "Calculate" in Chip Load Group – the spindle RPM is now estimated at 21429 RPM
11. May be OK, but check power requirements
12. Select spindle power checkbox.
13. Set required cut depth and width values (say 3.0 and 6.0)

14. Click "Calculate" button in Power Group
15. Required power is 68 Watts – looks OK.

Results:

- Spindle speed, 21429 RPM
- Feed Rate: 1500 mm/min

Example 2: Review a known speed and feed combination for materials properties, e.g. machining a hard wood with a 2 flute 12 mm cutter, with a cut depth of 2mm and a cut width of 6 mm (0.5 step-over)

1. Insert known speed of 800 mm/min and spindle speed of 10000 into respective fields.
2. Insert number of flutes (2)
3. Select chip load checkbox
4. Click "Calculate" in Chip Load Group
5. Chip load evaluated to 0.04.
6. Insert cutter diameter (12) into cutter diameter field.
7. Select cutting speed checkbox
8. Click "Calculate" button in Cutting Speed Group
9. Cutting speed evaluates to 376991

Results:

- Chip load is quite small, consider increasing, and re-evaluate feed rate.
- Cutting speed is quite high – or is it?"

Example 3: Cutting aluminium with a 3 flute 6 mm diameter cutter, with limits on available power – say 250 Watts. Estimate feed and speed.

1. Insert known properties for Aluminium from Materials Choice – then "Insert"
2. Set spindle power to 250 Watts
3. Set cut depth to 1 mm, set cut width to 6 mm
4. Select feed rate checkbox
5. Click "Calculate" button in Power Group
6. Feed rate evaluates to 1667 rpm.
7. Select spindle rpm checkbox
8. Click "Calculate" button in Chip Load Group
9. Spindle speed evaluates to 8335

Results:

- Feed rate: 1667 mm/min
- Spindle speed: 8337 rpm

These examples do not, in any way, represent real machining cases. The user must exercise due caution and undertake testing to ensure that the results are practically useful for their particular circumstances.

Use in Practice and Data Collection

For this program to be useful the following evaluation criteria are suggested:

1. Does it provide a logical way of evaluating speed and feed combinations that maintain their modelling consistency and providing the user with a good "feel" for what is going on?
2. Does it offers some new potential to explore speed and feed combinations that may provide improved machining conditions on your CNC machine?
3. Can the experience from users can be captured in the material properties data and made available to others.

Possible Further Developments

- Addition of Imperial unit options
- Review/choice of units used for parameters to meet "common" usage in your workshop.
- Integration with CamBam as a Plugin, to pick up some parameters from the selected MOPs, and possibly also pass updated values back to these MOPs.
- Addition of language translation options.
- Inclusion of error checking to avoid typos and any obvious parameter value inconsistencies.
- Correction and expansion of Material Choice examples from user contributions.
- Improvement of the UI.
- Feedback and suggestions are most welcome

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