Mathcad® for Mechanical Engineers

January 2009

Mathcad Overview

Mathcad has been the leading engineering calculation solution for more than 20 years

- Leading enterprise customers across multiple industries– 90% of Fortune 1000
- Industry leading products used by ~250K professionals
- Strong presence in higher education with ~500K users at over 2,000 universities

Award winning

- April 2006 Desktop Engineering announces Mathcad 13 as readers pick for Product of the Year
- Mathcad awarded four-star rating from PC Magazine - November 2004

3M
Airbus
BAE Systems
Bechtel Corp.
Boeing
Caterpillar
DuPont
Eli Lilly
General Dynamics
Hewlett-Packard
Honeywell
Hyundai Heavy
Lockheed Martin Corp.
Los Alamos National Lab
NASA
Northrop Grumman Corp.
Parson Brinkerhoff
Raytheon
Rolls Royce
Schlumberger
Siemens
Universal Studios
Westinghouse

Mathcad Value Proposition

Automates Process

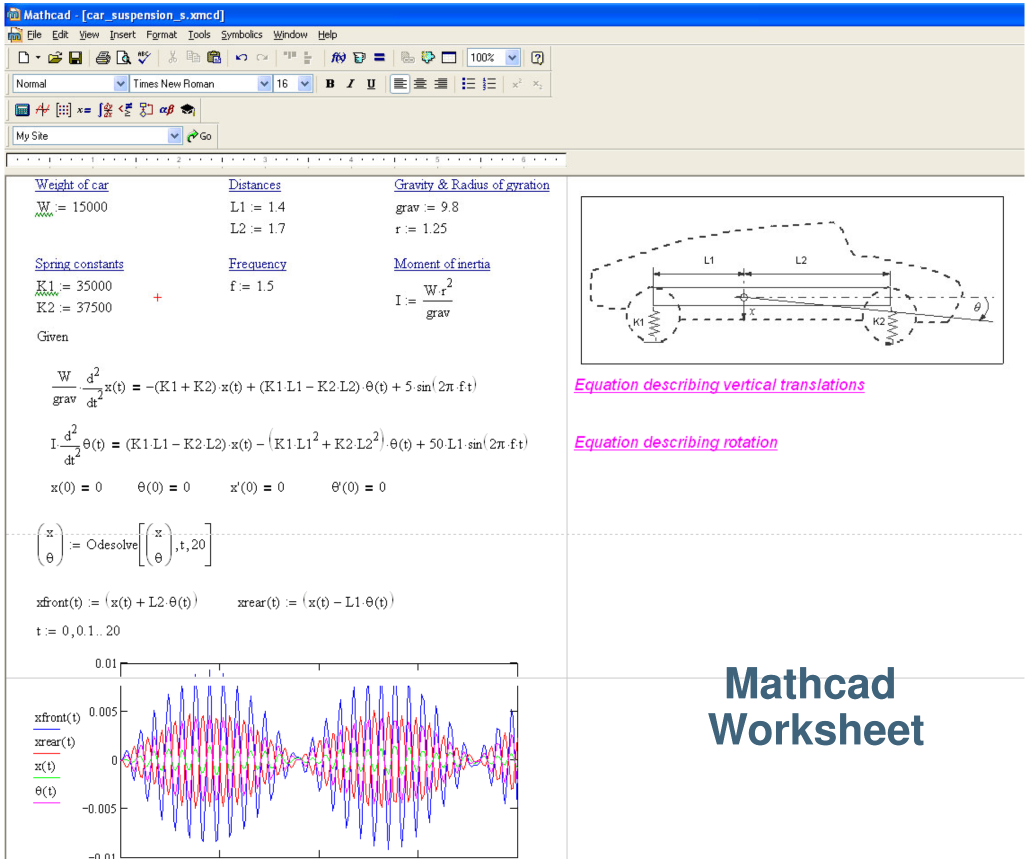
- Repeatable & auditable
  - Standard calculations
  - Proprietary calculations
- Live calculations
- Automatic “units” management

Communicates Engineering Knowledge

- Human readable calculations
- XML format enables automated publishing in downstream docs

Ensures Traceability

- Can connect
  - Calculations to design geometry
  - Results to customer and design requirements

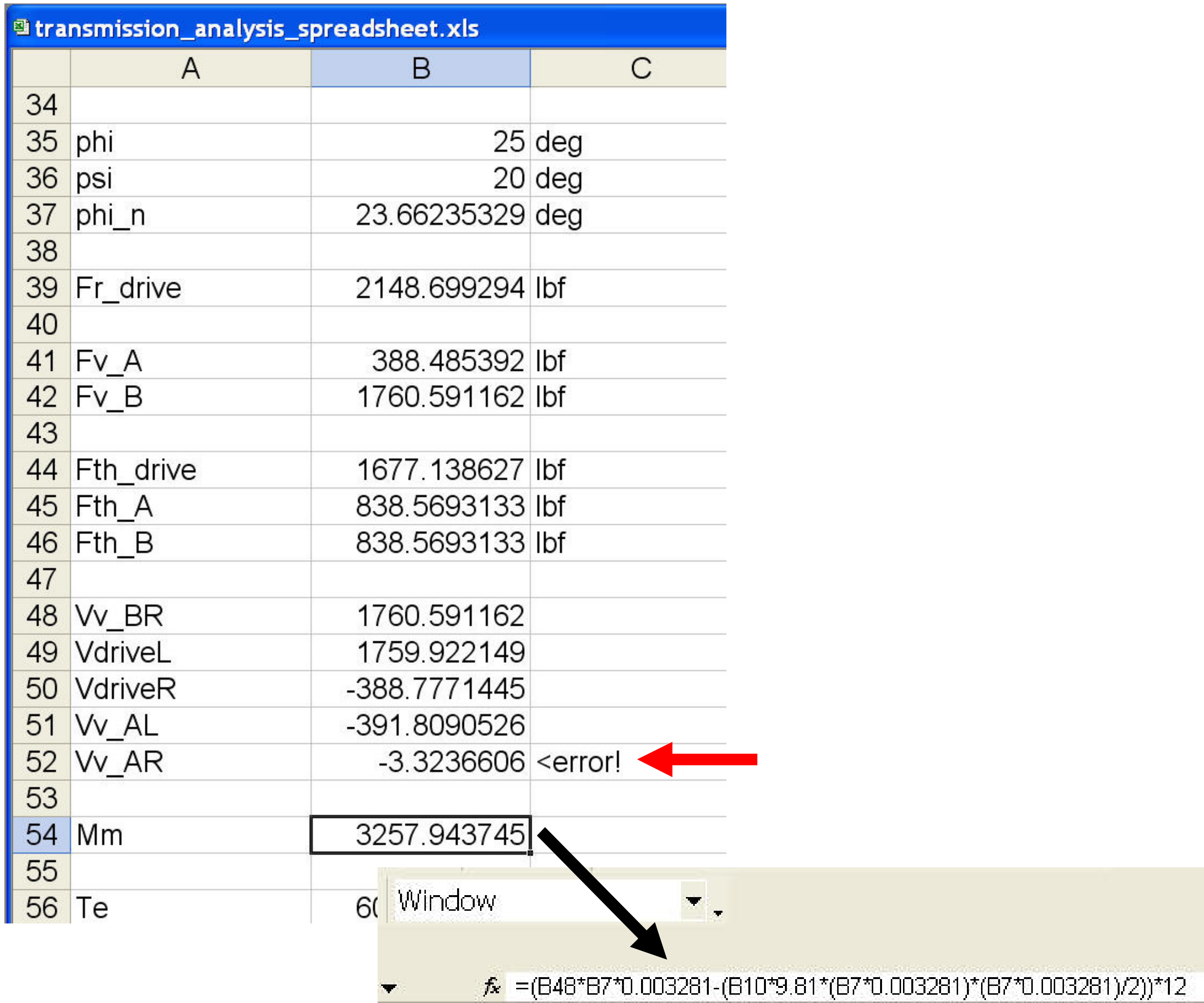


Mathcad Worksheet

Spreadsheet Methods Are Pervasive, but Not Ideal for Engineering Calculations

Issues

- Live calculation but formulae hard to read
- No “units” management
- Auditing difficult
- No support for advanced math calculations
  - Calculus
  - Differential equations
  - Etc….


transmission_analysis_spreadsheet.xls

	A	B	C
34			
35	phi	25	deg
36	psi	20	deg
37	phi_n	23.66235329	deg
38			
39	Fr_drive	2148.699294	lbf
40			
41	Fv_A	388.485392	lbf
42	Fv_B	1760.591162	lbf
43			
44	Fth_drive	1677.138627	lbf
45	Fth_A	838.5693133	lbf
46	Fth_B	838.5693133	lbf
47			
48	Vv_BR	1760.591162	
49	VdriveL	1759.922149	
50	VdriveR	-388.7771445	
51	Vv_AL	-391.8090526	
52	Vv_AR	-3.3236606	<error!
53			
54	Mm	3257.943745	
55			
56	Te	6(	

Mathcad, the Global Standard for Engineering Calculation Software

Engineering Focused

Intuitive

- Easy to use, whiteboard interface
- Natural math notation

Comprehensive

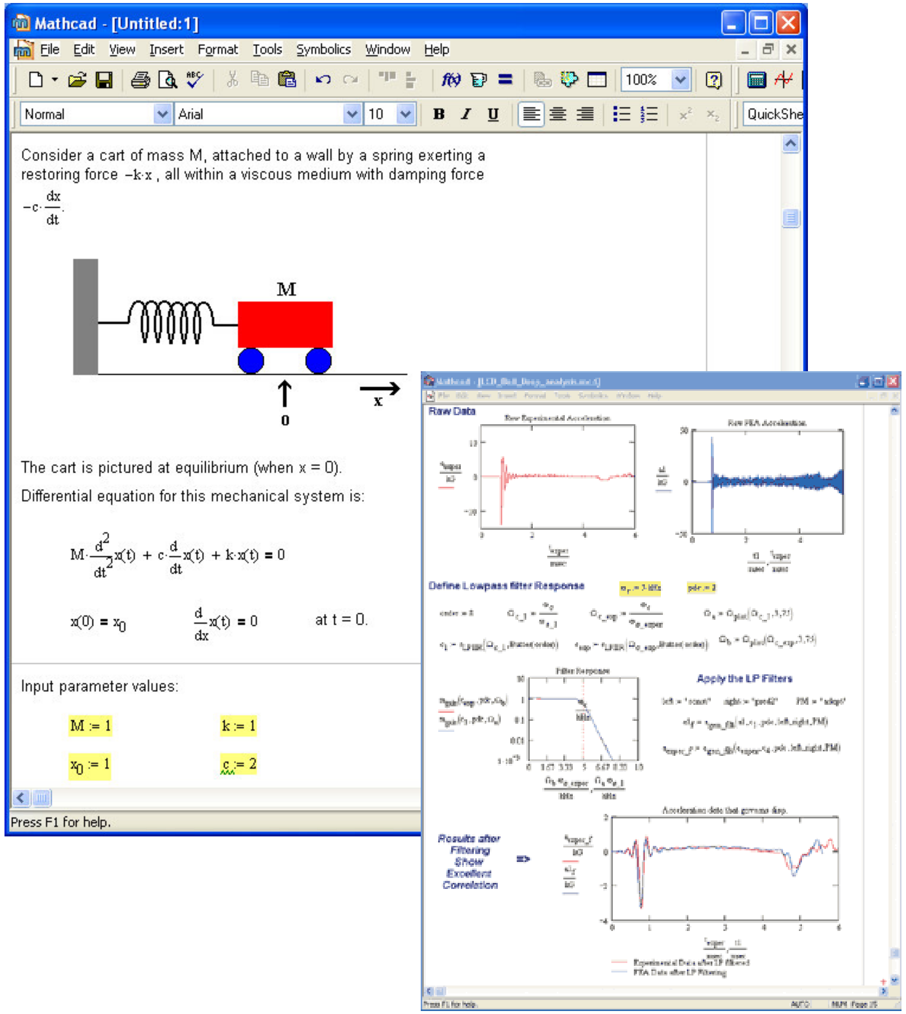
- Combines text, live math, graphics, and annotations in a single worksheet
- Unmatched breadth of application-powerful mathematics functionality, unit awareness

Interoperable

- Easily integrates with other engineering applications

Scalable

- Can extend functionality on the desktop and beyond the desktop



Highlevel Mathcad Capabilities

Live Numeric and Symbolic Calculations

Over 300 built-in functions and solvers

Vectors, Matrices

2-D and 3-D graphing

Units Capabilities

Programming capabilities

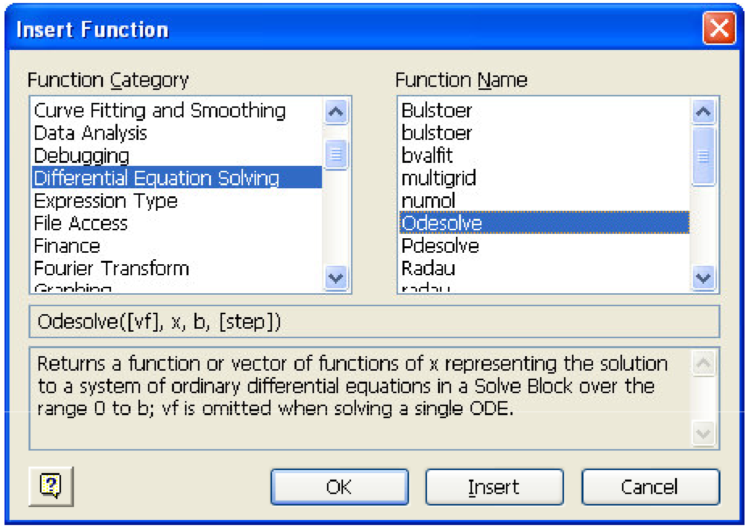
Unique Provenance capabilities

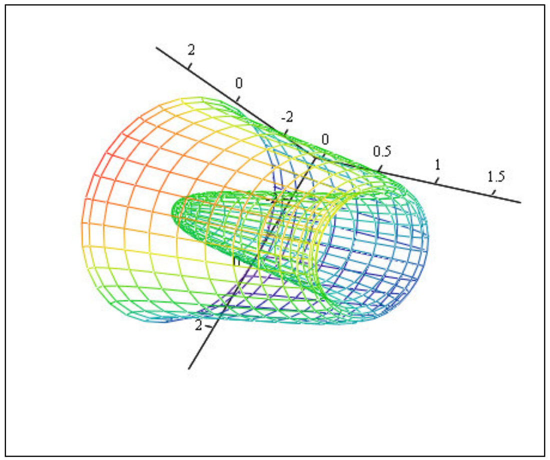
Publish to a variety of formats including pdf, html, etc.

Help, Tutorials, Quicksheets

$$\int_{1}^{10} x^2\,dx = 333 \qquad \int_{0}^{\pi} \cos(x) + \sin(x)\,dx = 2$$

$$\sum_{i} i^3 \rightarrow \frac{1}{4}\cdot i^4 - \frac{1}{2}\cdot i^3 + \frac{1}{4}\cdot i^2 \qquad \frac{d}{ds}\left[(3s)^2 + \frac{s}{2}\right] \rightarrow 18\cdot s + \frac{1}{2}$$





s

Mathcad for Machine Design and Analysis

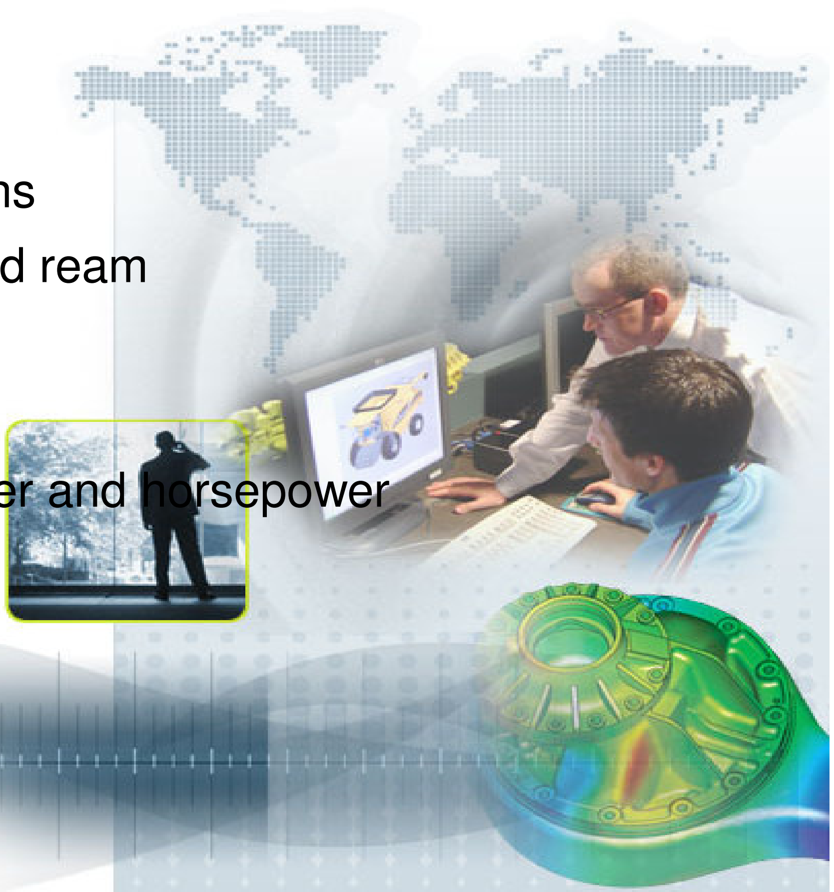
Mathcad's extensive libraries provide advanced math capabilities for Machine Design and Analysis:

- Energy stored in a rotating flywheel
- Shaft torque, horesepower and driver efficiency
- Pulley and gear loads on shafts
- Shaft reactions and bending moments
- Solid shafts in bending and torsion
- Deflection of a shaft carrying concentrated and uniform loads
- Speeds of gears and gear trains
- Selection of gear dimensions
- Selection of a shaft coupling for torque and thrust loads
- Curved spring design analysis
- Life of cyclically loaded mechanical springs

Mathcad for Metalworking

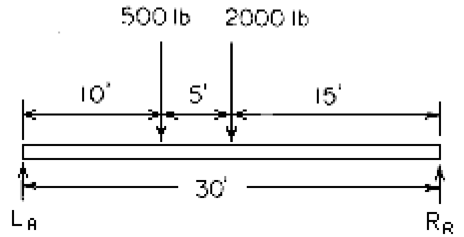
Mathcad's extensive libraries provide advanced math capabilities for Metalworking analysis:

- Total element time and total operation time
- Cutting speeds of various materials
- Dimensions of tapers and dovetails
- Angle and length of cut from given dimensions
- Time and power to drill, bore, countersink and ream
- Threading and tapping time
- Turret-lathe power input
- Milling cutting speed, time, feed, teeth number and horsepower
- Metal plating time and weight
- Shrink- and expansion-fit analyses
- Determining Brinell Hardness
- Optimum lot size in manufacturing



Shaft Reactions and Bending Moments

A 30-ft long steel shaft weighing 150 lb/ft of length has a 500-lb concentrated gear load 10 ft from the left end of the shaft and a 2000-lb concentrated pulley load 15 ft from the right end of the shaft. Determine the end reactions and the maximum bending moment in this shaft.



Given Parameters

Length of shaft: $L := 30 \cdot ft$

Weight of shaft: $W := 150 \cdot \frac{lb}{ft}$

Left-hand load: $w_L := 500 \cdot lbf$

Right-hand load: $w_R := 2000 \cdot lbf$

Lengths as shown in Figure 1a (below): $L_1 := 10 \cdot ft$ $L_2 := 5 \cdot ft$ $L_3 := 15 \cdot ft$

Calculate L_R by:

$$L \cdot L_R - \left[w_L \cdot (L_2 + L_3)\right] - \left[W \cdot g \cdot \left(L \cdot \frac{L}{2}\right)\right] - (w_R \cdot L_3) = 0$$

Solve for L_R using the symbolic processor.

$$L_R := \frac{1}{2} \cdot \frac{2 \cdot w_L \cdot L_2 + 2 \cdot w_L \cdot L_3 + W \cdot g \cdot L^2 + 2 \cdot w_R \cdot L_3}{L}$$

$$L_R = 3583.33\,lbf$$

Take moments about L_R to determine R_R.

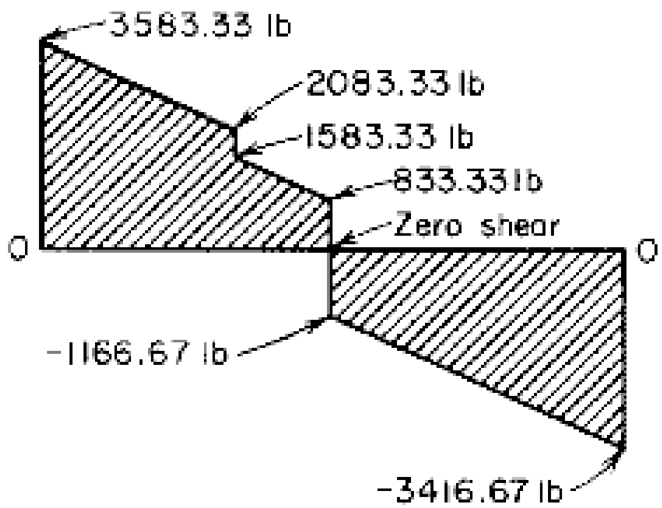
Calculate R_R by:

$$L \cdot R_R - (w_L \cdot L_1) - \left[W \cdot g \cdot \left(L \cdot \frac{L}{2}\right)\right] - \left[w_R \cdot (L_1 + L_2)\right] = 0$$

Solve for R_R using the symbolic processor.

$$R_R := \frac{1}{2} \cdot \frac{2 \cdot w_L \cdot L_1 + W \cdot g \cdot L^2 + 2 \cdot w_R \cdot L_1 + 2 \cdot w_R \cdot L_2}{L}$$

$$R_R = 3416.67\,lbf$$



Hydrostatic Multi-direction Bearing Analysis

Determine the lubricant pressure and flow requirements for the multi-direction hydrostatic bearing shown in Figure 18 (below) if the vertical coplanar forces acting on the plate are 164,000 lbf upward and downward, respectively, given the lubricant viscosity, film thickness, and bearing length (below).

Given Parameters

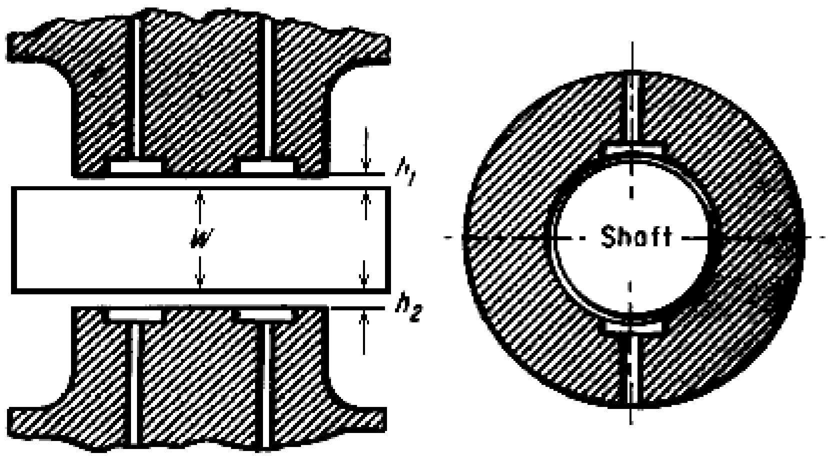
Plate load: $L_s := 164000 \cdot lbf$

Bearing length: $L := 7 \cdot in$

One-half the pad length: $a := 3.5 \cdot in$

Lubricant film thickness: $h := 0.005 \cdot in$

Lubricant viscosity: $\eta := 393 \cdot 10^{-7} \cdot \frac{lbf \cdot sec}{in^2}$



$$L_{s1}(h_l) := \frac{192 \cdot Q \cdot L^2 \cdot \eta}{K_q \cdot h_l^3}$$

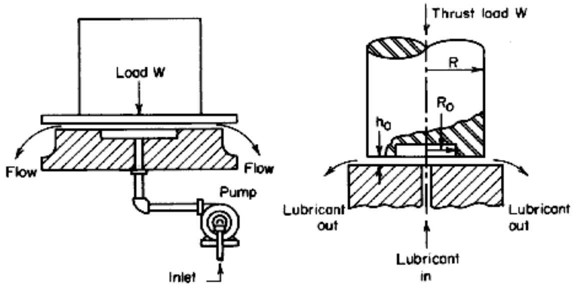
$$L_{s2}(h_l) := \frac{192 \cdot Q \cdot L^2 \cdot \eta}{K_q \cdot h_2(h_l)^3}$$

$$p_{i1}(L_{s1}) := \frac{K_p \cdot L_{s1}}{16 \cdot L^2}$$

$$p_{i2}(L_{s2}) := \frac{K_p \cdot L_{s2}}{16 \cdot L^2}$$

Hydrostatic Thrust Bearing Analysis

An oil-lubricated hydrostatic thrust bearing must support a load of 107,700 lbf. This vertical bearing has an outside diameter of 16 inches and a recess diameter of 10 inches.



Given Parameters

Load: $L := 107700 \cdot lbf$

Outside bearing diameter: $d := 16 \cdot in$

Outside bearing radius: $r := \frac{d}{2}$

Recess bearing diameter: $d_i := 10 \cdot in$

Recess bearing radius: $r_i := \frac{d_i}{2}$

Lubricant film thickness: $h := 0.006 \cdot in$

Absolute viscosity: $\eta := 42.4 \cdot 10^{-7} \cdot \frac{lbf \cdot sec}{in^2}$

Shaft rotational speed: $R := 750 \cdot \frac{rev}{min}$

$rev \equiv 1$

Below is Fuller's applied load equation.

$$L = P_i \cdot \frac{\pi}{2} \cdot \left(\frac{r^2 - r_i^2}{\ln\left(\frac{r}{r_i}\right)} \right)$$

Solve for the lubricant-supply inlet pressure.

$$P_i := \frac{2 \cdot L}{\pi \cdot \left(\frac{r^2 - r_i^2}{\ln\left(\frac{r}{r_i}\right)} \right)}$$

$$P_i = 826 \frac{lbf}{in^2}$$

Cutting Speeds for Various Materials

What spindle rpm is needed to produce a cutting speed of 150-ft/min on a 2-in diameter bar? What is the cutting speed of a tool passing through 2.5-in diameter material at 200 rpm? Compare the required rpm of a turret-lathe cutter with the available spindle speeds.

Given Parameters

Cutting speed: $C_b := 150 \cdot \frac{ft}{min}$

Diameter of bar: $d_b := 2 \cdot in$

Diameter of material: $d_m := 2.5 \cdot in$

RPM of tool: $R_m := 200 \cdot \frac{rev}{min}$

$rev \equiv 1$

Calculation Procedure

1. Compute the required spindle rpm

In a rotating tool, the spindle rpm is

$$R_b := \frac{C_b}{\pi \cdot d_b}$$

$$R_b = 286 \frac{rev}{min}$$

2. Compute the tool cutting speed

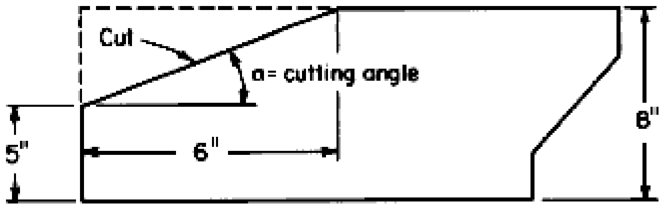
For a rotating tool, the cutting speed is

$$C_m := R_m \cdot \pi \cdot d_m$$

$$C_m = 131 \frac{ft}{min}$$

Angle and Length of Cut from Given Dimensions

At what angle must a cutting tool be set to cut the part? How long is the cut in this part?



Given Parameters

Length of opposite side (relative to angle a): $opp := (8 - 5) \cdot in$

Length of adjacent side (relative to angle a): $adj := 6 \cdot in$

Calculation Procedure

1. Compute the angle of the cut

Use trigonometry to compute the angle of the cut. Thus,

$$\tan(a) = \frac{opp}{adj}$$

Solve for a using the symbolic processor.

$$a := \operatorname{atan}\left(\frac{opp}{adj}\right)$$

$$a = 26.565\,deg$$

2. Compute the length of the cut

Use trigonometry to compute the length of cut. Thus,

$$\sin(a) = \frac{opp}{hyp}$$

Solve for hyp (the length of the cut) using the symbolic processor:

$$hyp := \frac{opp}{\sin(a)}$$

$$hyp = 6.7\,in$$

Determining Brinell Hardness

A 3000-kg load is put on a 10-mm diameter ball to determine the Brinell hardness of a steel. The ball produces a 4-mm-diameter indentation in 30 seconds. What is the Brinell hardness of the steel?

Given Parameters

Force on ball: $F := 3000 \cdot kg$

Ball diameter: $d_l := 10 \cdot mm$

Indentation diameter: $d_s := 4 \cdot mm$

Calculation Procedure

1. Determine the Brinell hardness by using an exact equation

The standard equation for determining the Brinell hardness is

$$BHN := \frac{F}{\left(\frac{\pi \cdot d_l}{2}\right) \cdot \left(d_l - \sqrt{d_l^2 - d_s^2}\right)}$$

$$BHN = 229 \frac{kg}{mm^2}$$

2. Compute the Brinell hardness by using an approximate equation

One useful approximate equation for Brinell hardness is

$$BHN_{approx} := \frac{4 \cdot F}{\pi \cdot d_s^2} - 10 \cdot \frac{kg}{mm^2}$$

$$BHN_{approx} = 228.7 \frac{kg}{mm^2}$$

This compares favorably with the exact formula. For Brinell hardness exceeding 200, the approximate equation gives results that are less than 0.1 percent in error.

Shrink- and Expansion-Fit Analyses

To what temperature must an SAE 1010 steel ring 24 inches in inside diameter be raised above a 68°F room temperature to expand it 0.004 inches if the linear coefficient of expansion of the steel is 0.0000068-in/(in ·°F)? To what temperature must a 2-inch diameter SAE steel shaft be reduced to fit it into a 1.997-inch diameter hole for an expansion fit? What cooling medium should be used?

Given Parameters

Linear coefficient of expansion of the steel: $K := 0.0000068 \cdot \frac{in}{in \cdot deg}$

Ring internal diameter: $d_r := 24 \cdot in$

Inches of expansion: $E := 0.004 \cdot in$

Shaft diameter: $d_s := 2 \cdot in$

Calculation Procedure

1. Compute the required shrink-fit temperature rise

The temperature rise needed to expand a metal ring a given amount before making a shrink fit is

$$T := \frac{E}{K \cdot d_r}$$

$T = 24.5$ deg temperature rise *above* room temperature

With a room temperature of 68°F, the final temperature of the ring must be

$68 \cdot deg + T = 92.5$ deg or higher

2. Compute the temperature for an expansion fit

Nitrogen, air, and oxygen in liquid form have a low boiling point, as does dry ice (solid carbon dioxide). Nitrogen and dry ice are considered the safest cooling media for expansion fits because both are relatively inert. Liquid nitrogen boils at -320.4°F and dry ice at -109.3°F. At -320°F liquid nitrogen will reduce the diameter of metal parts by the amount shown in Table 12 (below). Dry ice will reduce the diameter by about one-third the values listed in Table 12.

TABLE 12 Metal Shrinkage with Nitrogen Cooling

Metal	Shrinkage, in/in of shaft diameter
Magnesium alloys	0.0046
Aluminum alloys	0.0042
Copper alloys	0.0033
Cr-Ni alloys (18-8 to 18-12)	0.0029
Monel metals	0.0023
SAE steels	0.0022
Cr steels (5 to 27% Cr)	0.0019
Cast iron (not alloyed)	0.0017

With liquid nitrogen, the diameter of a 2-inch round shaft will be reduced by

$d_s \cdot 0.0022 = 0.0044$ in

given the value for SAE steels from Table 12. Thus, the diameter of the shaft at -320.4°F will be

$d_s - (d_s \cdot 0.0022) = 1.9956$ in

Since the hole is 1.997 inches in diameter, the liquid nitrogen will reduce the shaft size sufficiently.

If dry ice were used, the shaft diameter would be reduced by

$$\frac{d_s \cdot 0.0022}{3} = 0.00147 \text{ in}$$

giving a final shaft diameter of

$$d_s - \frac{d_s \cdot 0.0022}{3} = 1.99853 \text{ in}$$

This is too large to fit into a 1.997-inch hole. Thus, dry ice is unsuitable as a cooling medium.

Key Benefits of Standardizing on Mathcad

Improves Personal and Process Productivity

- Easy to use, automates key tasks, reduces errors
- Integrates with other applications used in the EE field
- Improves verification and validation of engineering designs

Captures critical IP locked within engineering calculations

Promotes company best practices and IP reuse

Supports compliance to standards

Reduces calculation related errors in the design process