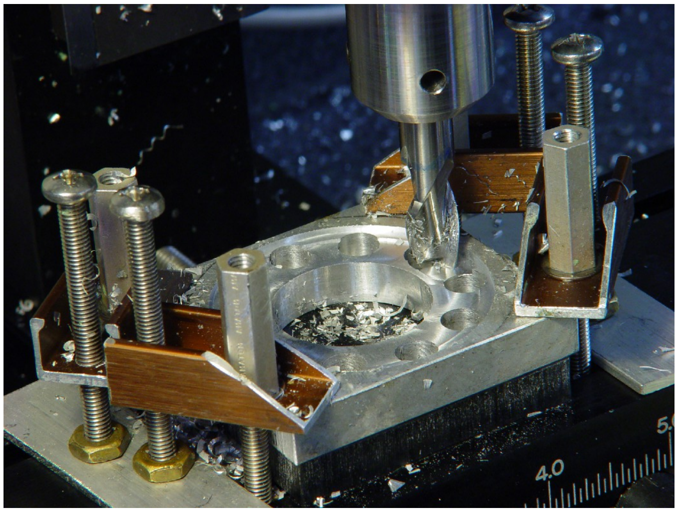
Tour Easy Chain Tensioner Pulley

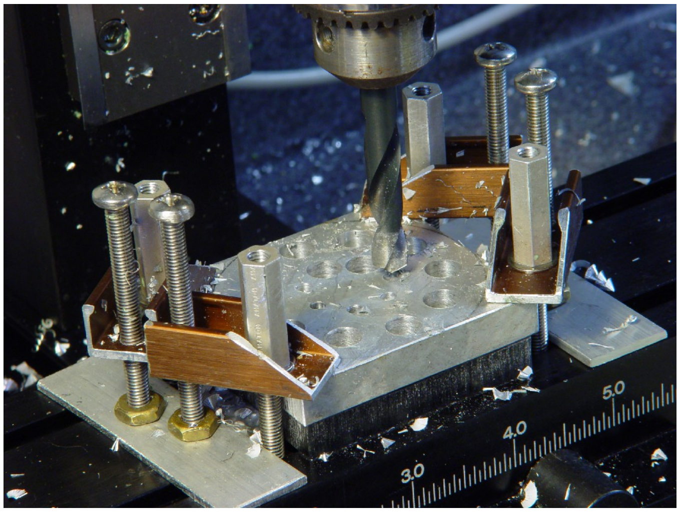
A pair of these pulleys on a spring-loaded hanger maintain tension on the chain of my Tour Easy recumbent bike. The original pulleys ran steel balls in plastic races: smooth, but not very durable.

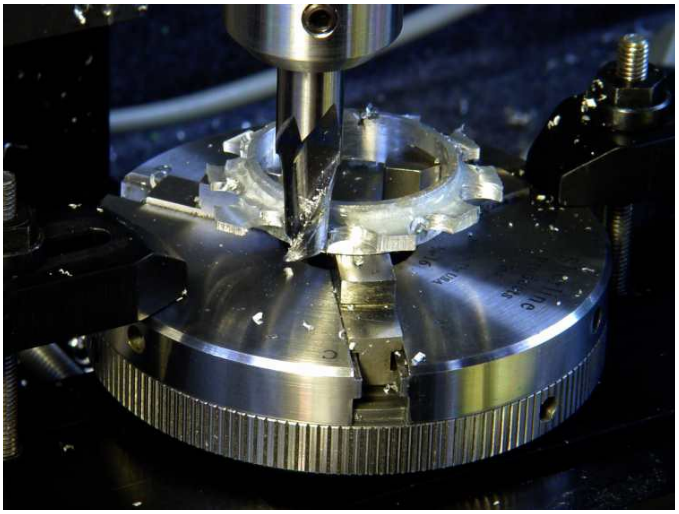
The code dates back to the days when EMC2 didn't have any useful programming constructs, so it consists largely of cut-and-paste chunks with very little math.

Don't write G-code like this now!

```
%
(Tour Easy chain tensioner idler pulleys - side 1)
(Ed Nisley KE4ZNU Jan 2006)
(Stock is 2-1/8" square 3/8" aluminum plate)
(XY origin is center of plate)
(Z origin is 5/16" = 0.3125 above sacrificial baseplate)
( ACHTUNG -- this is 1/16" =inside= the raw plate!!!)
( Touch Z=0 on one of the bearings atop a sacrificial plate)
(--------------------)
(-- Tool change position)
(all tools must be manually aligned to same Z value!)
#1001 =   3.000           (X)
#1002 =   0.000           (Y)
#1003 =   2.500           (Z)
(-- Z Positions)
#1010 =  0.063                        (surface of raw stock from Z origin)
#1011 =  [#1010 + 0.050]  (traverse clearance level)
#1012 =  [#1010 - 0.020]  (center drill level)
#1013 =  0.100            (peck depth for drilling)
#1014 = -0.400            (thru drilling level)
#1015 = -0.320            (thru milling level)
#1016 = -0.119            (flange level)
(-- Diameters)

#1020 = [0.374 / 2]       (actual mill diameter -> radius)
#1021 = [1.125 / 2]       (center hole diameter -> radius)
#1022 = [1.230 / 2]       (hub outside diameter -> radius)
#1023 = [1.475 / 2]       (flange outside diameter -> radius)
(-- Feeds)
#1051 =  2                (drilling feed)
#1052 =  7                (milling feed)
(--------------)
(Define conditions)
G90 (abs coords)
G20 (inches)
(--------------)
(Verify origin)
M05 (Spindle Off)
(msg, Aligned to XYZ zero? - Hit [Resume])
M00 (Wait for Resume)
(---------------)
(Center drill chain roller holes)
G00 Z #1003               (get air)
G00 X #1001 Y #1002       (tool change)
(msg, Install center drill, then hit [Resume])
M00 (Wait for Resume)
M03 (Spindle CW)
G00 X0 Y0
G00 Z#1011
G81 X0.0000 Y0.8090   Z#1012 R#1011 F#1051 (1)
G81 X0.4755 Y0.6545   Z#1012 R#1011 F#1051 (2)
G81 X0.7694 Y0.2500   Z#1012 R#1011 F#1051 (3)
```







```
G81 X0.7694 Y-0.2500  Z#1012 R#1011 F#1051 (4)
G81 X0.4755 Y-0.6545  Z#1012 R#1011 F#1051 (5)
G81 X-0.0000 Y-0.8090 Z#1012 R#1011 F#1051 (6)
G81 X-0.4755 Y-0.6545 Z#1012 R#1011 F#1051 (7)
G81 X-0.7694 Y-0.2500 Z#1012 R#1011 F#1051 (8)
G81 X-0.7694 Y0.2500  Z#1012 R#1011 F#1051 (9)
G81 X-0.4755 Y0.6545  Z#1012 R#1011 F#1051 (10)
(---------------)
(Center drill center bore to ease milling entry)
(G81 X0.0000 Y0.0000  Z#1012 R#1011 F#1051)
G81 X0.0000 Y0.3750   Z#1012 R#1011 F#1051
G81 X0.2932 Y0.2338   Z#1012 R#1011 F#1051
G81 X0.3656 Y-0.0834  Z#1012 R#1011 F#1051
G81 X0.1627 Y-0.3379  Z#1012 R#1011 F#1051
G81 X-0.1627 Y-0.3379 Z#1012 R#1011 F#1051
G81 X-0.3656 Y-0.0834 Z#1012 R#1011 F#1051
G81 X-0.2932 Y0.2338  Z#1012 R#1011 F#1051
(---------------)
(Pilot drill chain roller holes)
G00 Z #1003               (get air)
G00 X #1001 Y #1002       (tool change)
(msg, Install 3/16" drill, then hit [Resume])
M00 (Wait for Resume)
M03 (Spindle CW)
G00 X0 Y0
G00 Z#1011
G83 X0.0000 Y0.8090   Z#1014 R#1011 Q#1013 F#1051  (1)
G83 X0.4755 Y0.6545   Z#1014 R#1011 Q#1013 F#1051  (2)
G83 X0.7694 Y0.2500   Z#1014 R#1011 Q#1013 F#1051  (3)
G83 X0.7694 Y-0.2500  Z#1014 R#1011 Q#1013 F#1051  (4)
G83 X0.4755 Y-0.6545  Z#1014 R#1011 Q#1013 F#1051  (5)
G83 X-0.0000 Y-0.8090 Z#1014 R#1011 Q#1013 F#1051  (6)
G83 X-0.4755 Y-0.6545 Z#1014 R#1011 Q#1013 F#1051  (7)
G83 X-0.7694 Y-0.2500 Z#1014 R#1011 Q#1013 F#1051  (8)
G83 X-0.7694 Y0.2500  Z#1014 R#1011 Q#1013 F#1051  (9)
G83 X-0.4755 Y0.6545  Z#1014 R#1011 Q#1013 F#1051  (10)
(---------------)
(Pilot drill holes in center bore)
(G83 X0.0000 Y0.0000  Z#1014 R#1011 Q#1013 F#1051)
G83 X0.0000 Y0.3750   Z#1014 R#1011 Q#1013 F#1051
G83 X0.2932 Y0.2338   Z#1014 R#1011 Q#1013 F#1051
G83 X0.3656 Y-0.0834  Z#1014 R#1011 Q#1013 F#1051
G83 X0.1627 Y-0.3379  Z#1014 R#1011 Q#1013 F#1051
G83 X-0.1627 Y-0.3379 Z#1014 R#1011 Q#1013 F#1051
G83 X-0.3656 Y-0.0834 Z#1014 R#1011 Q#1013 F#1051
G83 X-0.2932 Y0.2338  Z#1014 R#1011 Q#1013 F#1051
(---------------)
(Drill chain roller holes)
G00 Z #1003               (get air)
G00 X #1001 Y #1002       (tool change)
(msg, Install 19/64" drill, then hit [Resume])
M00 (Wait for Resume)
M03 (Spindle CW)
G00 X0 Y0
G00 Z#1011
G81 X0.0000 Y0.8090   Z#1014 R#1011 F#1051 (1)
G81 X0.4755 Y0.6545   Z#1014 R#1011 F#1051 (2)
G81 X0.7694 Y0.2500   Z#1014 R#1011 F#1051 (3)
G81 X0.7694 Y-0.2500  Z#1014 R#1011 F#1051 (4)
G81 X0.4755 Y-0.6545  Z#1014 R#1011 F#1051 (5)
G81 X-0.0000 Y-0.8090 Z#1014 R#1011 F#1051 (6)
G81 X-0.4755 Y-0.6545 Z#1014 R#1011 F#1051 (7)
G81 X-0.7694 Y-0.2500 Z#1014 R#1011 F#1051 (8)
G81 X-0.7694 Y0.2500  Z#1014 R#1011 F#1051 (9)
G81 X-0.4755 Y0.6545  Z#1014 R#1011 F#1051 (10)
(---------------)
(Drill holes in center bore)
(G81 X0.0000 Y0.0000  Z#1014 R#1011 F#1051)
G81 X0.0000 Y0.3750   Z#1014 R#1011 F#1051
G81 X0.2932 Y0.2338   Z#1014 R#1011 F#1051
G81 X0.3656 Y-0.0834  Z#1014 R#1011 F#1051
G81 X0.1627 Y-0.3379  Z#1014 R#1011 F#1051
G81 X-0.1627 Y-0.3379 Z#1014 R#1011 F#1051
G81 X-0.3656 Y-0.0834 Z#1014 R#1011 F#1051
G81 X-0.2932 Y0.2338  Z#1014 R#1011 F#1051
(---------------)
(Mill center bore)
M05 (Spindle Off)
G00 Z #1003
G00 X #1001 Y #1002
(msg, Install 3/8 mill, then hit [Resume])
M00 (Wait for Resume)
(msg, Check for skim cut on each first pass)
(msg, Mill center bore)
M03 (Spindle CW)
G00 X0 Y0
G00 Z#1011
#991 = [#1021 - #1020]    (X for hole start)
#992 = 0                  (Y for hole start)
#993 = [#1010 - #1015]    (total depth to mill)
#994 = [#993 / 6]         (depth per pass)
#995 = #1010              (Z starting location)
G00 X#991 Y#992 Z#995     (to top surface)
G02 X#991 Y#992 I[0 - #991] J[0 - #992] F#1052
#995 = [#995 - #994]      (1 - step down)
G01 Z#995 F#1051
G02 X#991 Y#992 I[0 - #991] J[0 - #992] F#1052
#995 = [#995 - #994]      (2 - step down)
G01 Z#995 F#1051
G02 X#991 Y#992 I[0 - #991] J[0 - #992] F#1052
#995 = [#995 - #994]      (3 - step down)
G01 Z#995 F#1051
G02 X#991 Y#992 I[0 - #991] J[0 - #992] F#1052
#995 = [#995 - #994]      (4 - step down)
G01 Z#995 F#1051
G02 X#991 Y#992 I[0 - #991] J[0 - #992] F#1052
#995 = [#995 - #994]      (5 - step down)
G01 Z#995 F#1051
G02 X#991 Y#992 I[0 - #991] J[0 - #992] F#1052
#995 = [#995 - #994]      (6 - step down)
G01 Z#995 F#1051
G02 X#991 Y#992 I[0 - #991] J[0 - #992] F#1052
G00 Z#1011                (get air)
(---------------)
(Mill hub to finished thickness)
(msg, Mill hub thickness)
#991 = [#1021 + #1020]    (X for start)
#991 = [#991 - 0.050]     (offset for nice edge)
#992 = 0                  (Y for start)
#993 = [#1010]            (total depth to mill)
#994 = [#993 / 2]         (depth per pass)
#995 = #1010              (Z at start)
G00 X#991 Y#992 Z#995     (to top surface)
G02 X#991 Y#992 I[0 - #991] J[0 - #992] F#1052
#995 = [#995 - #994]      (1 - step down)
G01 Z#995 F#1051
G02 X#991 Y#992 I[0 - #991] J[0 - #992] F#1052
#995 = [#995 - #994]      (2 - step down)
G01 Z#995 F#1051
G02 X#991 Y#992 I[0 - #991] J[0 - #992] F#1052
G00 Z#1011                (get air)
(---------------)
(Mill flange)
(msg, Mill flange)
#991 = [#1022 + #1020]    (X for start)
#992 = 0                  (Y for start)
#993 = [#1010 - #1016]    (total depth to mill)
#994 = [#993 / 4]         (depth per pass)
#995 = #1010              (Z at start)
G00 X#991 Y#992 Z#995     (to top surface)
G03 X#991 Y#992 I[0 - #991] J[0 - #992] F#1052
#995 = [#995 - #994]      (1 - step down)
G01 Z#995 F#1051
G03 X#991 Y#992 I[0 - #991] J[0 - #992] F#1052
#995 = [#995 - #994]      (2 - step down)
G01 Z#995 F#1051
G03 X#991 Y#992 I[0 - #991] J[0 - #992] F#1052
#995 = [#995 - #994]      (3 - step down)
G01 Z#995 F#1051
G03 X#991 Y#992 I[0 - #991] J[0 - #992] F#1052
#995 = [#995 - #994]      (4 - step down)
G01 Z#995 F#1051
G03 X#991 Y#992 I[0 - #991] J[0 - #992] F#1052
G00 Z#1011                (get air)
(--------------)
M05 (Spindle Off)
G00 Z #1003
G00 X #1001 Y #1002
(msg, Done with Side 1!)
M30
%
```

Storm Door Latch Pull

The hardware inside the storm door latches on our house wore out after only half a century: nothing lasts! New latches don't fit and we weren't willing to replace the doors, so I got some quality shop time.

I used this latch pull as an example in my Along the G-code Way column in Digital Machinist magazine (Issues 3.4 and 4.1), showing how to calculate the coordinates of the points required for all the edges and arcs.

This G-code requires a current versions of EMC2; the most recent version automatically inserts fillets on concave corners when they're required.

```
%
( Storm door latch pull )
( Inside milling, clamped along two sides)
( Ed Nisley - Jan 2009 )
(-----------------)
#1000 = -75.00           (tool change XYZ)
#1001 =   0.00
#1002 =  75.00
#1004 =   1.00           (traverse clearance)

#1113 =   1                      (tool slot holding this
cutter)

#1120 = [100 * 12 * 25.4] (cutting speed, surface ft/min >
mm/min)
#1121 = 3000                     (spindle RPM)
#1122 = 50                       (milling feed, mm/min)
#1123 = 500                      (alignment speed, no contact
)

#1130 = [0.060 * 25.4]           (max Z cut depth, inches ->
mm)
#1131 = 0.75                     (milling cut depth)
#1132 = FUP[#1130 / #1131]       (number of cutting passes)
#1133 = [#1130 / #1132]          (adjusted depth per pass)

#1200 =  1.60                    (inside corner fillet radius
)
```

```
(-----------------)
(Part corner coordinates)
(Long body axis parallel to Y, "near" is to front of table =
low Y)
(Symmetrical about Y axis, all in X+ range)
( X = even, Y=odd)
(Inside material contour, X+ half)

#2000 =  0.00    (center of bottom)
#2001 =  8.30
#2010 =  4.40    (LR corner)
#2011 =  8.30
#2020 =  4.40    (P0: start of neckdown)
#2021 = 28.30
#2030 =  3.00    (P1: end of neckdown)

#2031 = 29.70
```

```
#2040 =  3.00    (UR corner)
#2041 = 36.80

(-----------------)
(Calculate fairing point coordinates)

#<_radius> = #1200
        (fillet inside corner radius)

#<_phi> = ABS [ ATAN [#2030 - #2020] / [#2031 - #2021] ]
(neckdown angle)
#<_theta> = [90 - [#<_phi>]]
        (angle of perpendicular to neckdown)

#<_CBx> = [#<_radius> * COS [#<_phi>]]
        (X distance PC to PB)
#<_CBy> = [#<_radius> * SIN [#<_phi>]]
        (Y distance PC to PB)

#<_PAx> = [#2020]
        (X coord of PA - side point)

#<_PCx> = [#<_PAx> - #<_radius>]
        (X coord of PC - arc center point)

#<_PBx> = [#<_PCx> + #<_CBx>]
        (X coord of PB - neckdown tangent point)
#<_PBy> = [#2021 + [#<_radius> - #<_CBx>] * TAN [#<_theta>]]
        (Y coord of PB - neckdown tangent point)

#<_PCy> = [#<_PBy> - #<_CBy>]
        (Y coord of PC - arc center point)

#<_PAy> = [#<_PCy>]
        (Y coord of PA - side point)

(-----------------)
(Routine to cut outline)
(#1 = new Z level for first cut)
(This is interior cut, go CW for conventional milling)

O100 SUB

G1 X[0-[#2010 - #1200]] Y#2011 Z#1
        (ramp down along slot bottom)
G2 X[0-#2010] Y[#2011 + #1200] I0 J#1200
( ... LL corner)

G1 X[0-#2020] Y#<_PAy>
        (slot side L to fillet start)

G2 X[0-#<_PBx>] Y#<_PBy> I#<_radius> J0
        (fillet)
G1 X[0-#2030] Y#2031
        (fillet to neck)

G1 X[0-#2040] Y[#2041 - #1200]
        (neck L)
G2 X[0-[#2040 - #1200]] Y#2041 I#1200 J0
(fillet to top)

G1 X[#2040 - #1200] Y#2041
        (across the top to UR fillet)

G2 X#2040 Y[#2041 - #1200] I0 J[0-#1200]
(fillet to neck)
G1 X#2030 Y#2031
(neck R)

G1 X#<_PBx> Y#<_PBy>
        (neck to fillet)
G2 X#<_PAx> Y#<_PAy> I[0 - #<_CBx>] J[0 - #<_CBy>]
        (fillet to slot R)

G1 X#2010 Y[#2011 + #1200]
        (slot to LR corner)
G2 X[#2010 - #1200] Y#2011 I[0-#1200] J0
(fillet to slot bottom)

G1 X#2000 Y#2001
(return to middle)

O100 ENDSUB

(-----------------)
(Define setup)

G90                                 (absolute units)
G21                                 (metric units)
S #1121                   (set spindle speed)
F #1122                   (set milling feed)

(-----------------)
(debug,Align XY=0 origin, Z=0 at surface, RPM = #1121, hit
[Resume])

M0                                  (wait for Resume)
M3                                  (spindle CW)
G0 Z#1002                           (get big air for alignment)

(-----------------)
(Start cutter compensation)
(Internal hole, so we go CW around the cutout)

T#1113 M6                           (fake toolchange for Axis
backplot)

G0 X#2020 Y#2021          (alignment move to R side)
G42 D#1113                          (tool to right, D = cutter)

G1 X[#2000 + #1200] Y[#2001 + #1200] F#1123        (entry move
1 to start of entry arc)
G2 X#2000 Y#2001 I[0-#1200] J0 F#1123              (entry move
2 along arc to middle bottom)

(-----------------)
(Commence cutting!)

G0 Z#1004                           (to traverse level)

#900 = 0                            (pass counter - start at
surface)
#901 = 0.00                         (initial Z)

F#1122                              (milling speed)

O200 DO                             (mill outline)

O100 CALL [#901]          (do a pass around the outline)

#900 = [#900 + 1]                   (tick loop counter)
#901 = [#901 - #1133]     (next Z level)

O200 WHILE [#900 LE #1132]          (mill outline)

G1 X[0-[#2010 - #1200]] Y#2011      (trim final ramp)

(-----------------)
M5                                  (spindle off)
G0 Z#1002                           (get air)

G40                                 (cutter comp off)
G0 X#1000 Y#1001          (return home)
(msg,Done!)
M30
%
```

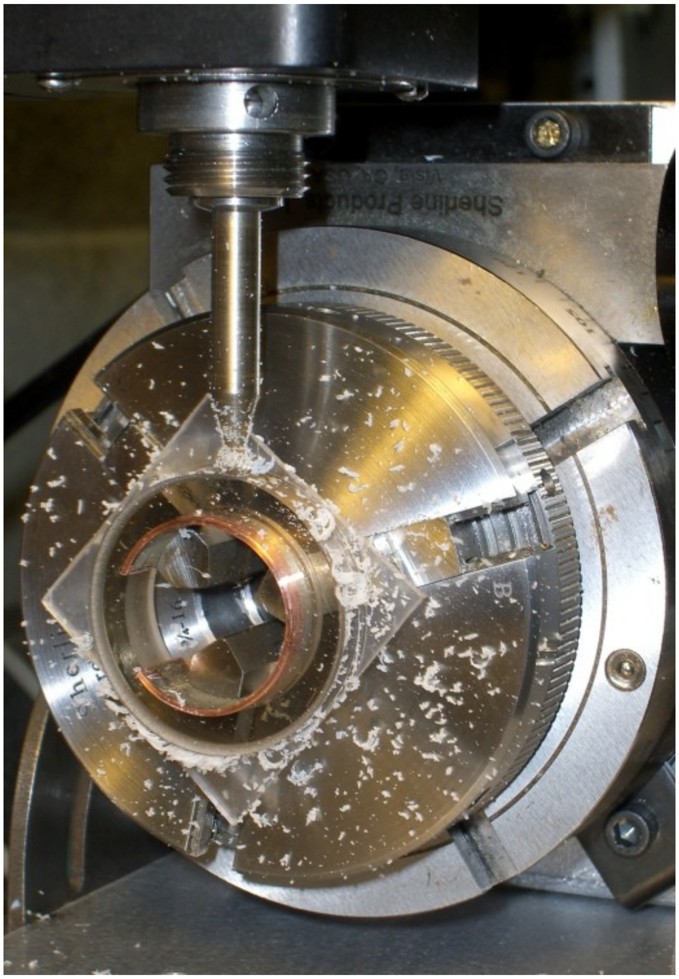
Sherline Counterweight Gantry

This project didn't require much CNC, but the pulley is a good example of how helical milling can produce IDs and ODs of whatever size you need.

I milled the ID with the chunk of polycarbonate clamped to a sacrificial plate, then grabbed the ID in a three-jaw chuck to mill the OD, and finally mounted the chuck on a rotary table to cut the pulley groove. The ball mill should be presented to the pulley OD at about 3 o'clock where their equators match up, but this setup worked OK.

You, on the other hand, should machine the groove using circular interpolation with a G2 or G3 instruction, without a rotary table!

```
%
(Outer diameter of pulley used on Sherline mill counterweight)
(This could be a lathe project, but it's easier to clamp on
the mill)
(Add drive dog pin inside final OD to engage chuck jaw)
(11 Jan 2009)
(XY origin at center, Z=0 at surface)

#<_Rough> = 1
#<_Finish> = 1

(-- Tool change position)

#5161 =   0                         (X)
#5162 =   0                         (Y)
#5163 =   [50.0 / 25.4]             (Z)

(-- Z Positions)

#<_Traverse_Z>   =  35.0            (Z traverse clearance)

(-- Part dimensions)

#<_Thickness>             = 6.5           (stock thickness)
#<_Pulley_Dia>            = 37.0          (outer diameter)

#<_Pulley_Radius>         = [#<_Pulley_Dia> / 2]

#<_Tool_Dia>              = 9.47          (endmill dia - 3/8
inch)
```



```
#<_Tool_Slot>            = 6

#<_Cut_Finish>           = 0.8           (leave this width
for finish cut)

#<_Tool_Radius>          = [#<_Tool_Dia> / 2]

(-- Calculate cutting params)

#<_Cut_MaxDepth> = 2.0            (max Z cut depth)
#<_Num_Passes>           = FUP [#<_Thickness> /
#<_Cut_MaxDepth>]
#<_Cut_Depth>            = [#<_Thickness> / #<_Num_Passes>]

(-- Speeds & Feeds)

#<_Mill_RPM>     = 2000           (milling RPM)
#<_Mill_Feed>    = 200            (milling feed)
#<_Traverse_Feed> = 500           (traverse speed - no
contact!)

(----- Start cutting)

G90                      (absolute coordinates)
G21                      (METRIC units)

M5                       (spindle off)

(msg,Verify origin = center of part, Z=0 at surface)
M0                       (wait for resume)
G0 Z[#5163 * 25.4]       (get air, then to tool change)
G28
T #<_Tool_Slot> M6       (fake tool change for Axis backplot)

(debug,Insert #<_Tool_Dia> mm end mill, set #<_Mill_RPM> RPM,
hit Resume)
M0                       (wait for resume)
M3                       (spindle CW)

(--- helical-cut rough outline)

O10 IF [#<_Rough>]

G0 X[0 - #<_Pulley_Radius>] Y0                     (set up for
cutter comp)

G41.1 D[#<_Tool_Dia> + #<_Cut_Finish>]
        (cutter comp on left)
G2 X[#<_Pulley_Radius>] I[#<_Pulley_Radius>]
F#<_Traverse_Feed>       (CW entry arc to right side)

G0 Z0
F[#<_Mill_Feed> / 2]

#<_Pass> = 0             (iteration counter)
#<_ZLevel> = 0           (current Z-axis level)

O100 DO

G2 X[#<_Pulley_Radius>] I[0 - #<_Pulley_Radius>] Z#<_ZLevel>
        (helical down)

#<_ZLevel> = [#<_ZLevel> - #<_Cut_Depth>]

#<_Pass> = [#<_Pass> + 1]

O100 WHILE [#<_Pass> LE #<_Num_Passes>]

G2 X[#<_Pulley_Radius>] I[0 - #<_Pulley_Radius>]
(remove ramp to final level)

G40                      (comp off)

G0 X#<_Pulley_Dia> Y0    (move away from part)

G0 Z[#5163 * 25.4]       (get air)

O10 ENDIF

(--- helical-cut finish outline)

O20 IF [#<_Finish>]

G0 X[0 - #<_Pulley_Radius>] Y0                     (set up for
cutter comp)

G41.1 D[#<_Tool_Dia>]                      (cutter comp on
left)
G2 X[#<_Pulley_Radius>] I[#<_Pulley_Radius>]
F#<_Traverse_Feed>       (CW entry arc to right side)

G0 Z0
F[#<_Mill_Feed>]

#<_Pass> = 0             (iteration counter)
#<_ZLevel> = 0           (current Z-axis level)

O200 DO

G2 X[#<_Pulley_Radius>] I[0 - #<_Pulley_Radius>] Z#<_ZLevel>
        (helical down)

#<_ZLevel> = [#<_ZLevel> - #<_Cut_Depth>]

#<_Pass> = [#<_Pass> + 1]

O200 WHILE [#<_Pass> LE #<_Num_Passes>]

G2 X[#<_Pulley_Radius>] I[0 - #<_Pulley_Radius>]
        (remove ramp to final level)

G40                      (comp off)

G0 X#<_Pulley_Dia> Y0    (move away from part)

O20 ENDIF

(-- cleanup)

M5                       (spindle off)
G0 Z [#5163 * 25.4]      (get air, then to tool change)
G28

M30

%
```

Radio Tote Box Adapter Plate

My amateur radio go-kit (a plastic tool box) has two compartments that seemed ideal for all the adapter that you must have to connect RF gadgets to each other. The catch was that things kept getting lost or strayed. So I machined a plate with a hole for each adapter.

Helical milling makes holes of any dimension you need and a bit of G-code allows for simple stepped holes, too.

Because the sides of the compartments aren't straight, the G-code must compute the intersection point of two arcs and then add a fillet arc that smoothly joins them.

This is old code; don't write new G-code this way!

```
%
(Radio carry-all box - BNC adapter plate outline)
(March 2006 Ed Nisley KE4ZNU)
(3/8" polycarbonate sheet, about 100x70 mm, long axis parallel to X)
(Clamp internally using connector holes)
(Origin is to near-center edge of stock, which will be rear in toolbox)
( ... so "far" here is the curved front face of the plate)
(It is symmetric about X=0 and calculations are for right half)
( ... we mill counterclockwise starting from the origin for conventional milling)
(1/4" mill must be tool 4 for proper cutter diameter compensation)
(****** METRIC UNITS ***********)
(--------------------)
(-- Tool change position)
(all tools must be manually aligned to same Z value!)
#1001 =  -70             (X)
#1002 =    0             (Y)
#1003 =   70             (Z)
(-- Z Positions)
#1011 =   1.0            (traverse clearance)
#1013 = -10.0            (thru mill level)
(-- Measured or eyeballed values)
#1021 = [93.0 / 2]       (X maximum at center of side arc = half of total width)
#1022 = 65.0             (Y maximum at center of far arc)
#1023 =  1.0             (X bump on side arc = m = height of sector)
#1024 =  2.5             (Y bump on far arc = m)
#1025 = 78.0             (X width of far arc = c = width of sector)
#1026 = 57.0             (Y width of side arc = c)
#1027 =  7.0             (rf radius of far fairing circle)
(--- Geometry calculations)
(    Find side arc radii and center points)
#2001 = 0                        (P2X X centerline of far arc)
#2002 = [#1022 / 2]              (P1Y Y centerline of side arcs)
#2003 = [[#1023**2 + [#1026**2 / 4]] / [2 * #1023]]
(R1 radius of side arc)
#2004 = [[#1024**2 + [#1025**2 / 4]] / [2 * #1024]]
(R2 radius of far arc)
```

```
#2005 = [#1021 - #2003]                    (P1X X coord of
side arc center)
#2006 = [#1022 - #2004]                    (P2Y Y coord of far
arc center)
#2007 = [ASIN[[#1026 / 2] / #2003]]                (THETA1
angle to side arc near tangent point)
(---  near corner = straight line with side arc)
(     note order of calculation!)
#2013 = [#1021 - #1023]                            (X @
intersect corner circle and side arc)
#2014 = [#2002 - [#1026 / 2]]                      (Y @ ")
#2015 = [#2014/[1-SIN[#2007]]]                     (radius of
near corner circle)
#2011 = [#1021 - #1023 - [#2015 * COS[#2007]]]     (X @
tangent intersect near side and corner circle)
#2012 = 0                                          (Y @ ")
(---  far corner = intersection of far and side arcs)
#2021 = [#2001 - #2005]                         (e = P2X - P1X
)
#2022 = [#2006 - #2002]                         (f = P2Y - P1Y
)
#2023 = sqrt[#2021**2 + #2022**2]                (p = sqrt e^2
+ f^2)
#2024 = [#2003 - #1027]                         (r = R1 - rf)
#2025 = [#2004 - #1027]                         (s = R2 - rf)
#2027 = [[#2023**2 + #2024**2 - #2025**2] / [2 * #2023]]
(k = p^2 + r^2 - s^2 / 2p)
#2028 = [#2027 / #2023]                            (k/p -
useful value)
#2029 = SQRT[#2024**2 - #2027**2]                  (radical -
useful value)
#2031 = [#2005 + #2021*#2028 - [#2022/#2023]*#2029]
(P3X X = P1X + ek/p - f/p sqrt r^2 - k^2)
#2032 = [#2002 + #2022*#2028 + [#2021/#2023]*#2029]
(P3Y Y = P1Y + fk/p + e/p sqrt r^2 - k^2)
#2035 = ATAN[#2032 - #2002] / [#2031 - #2005]         (THETA1
= atan P3Y-P1Y / P3X-P1X)
#2036 = ATAN[#2032 - #2006] / [#2031 - #2001]         (THETA2
= atan P3Y-P2Y / P3X-P2X)
(---  tangent intersection points)
#2041 = [#2005 + #2003 * COS[#2035]]                     (AX =
P1X + R1 * COS THETA1)
#2042 = [#2002 + #2003 * SIN[#2035]]                     (AY =
P1Y + R1 * SIN THETA1)
#2043 = [#2001 + #2004 * COS[#2036]]                     (BX =
P2X + R2 * COS THETA2)
#2044 = [#2006 + #2004 * SIN[#2036]]                     (BY =
P2Y + R2 * SIN THETA2)
(--- Tool diameters)
#1061 =  [6.32 / 2]       (1/4" cutter -> radius -- must match
Tool 4 value!)
(-- Feeds)
#1071 = 100               (milling feed)
#1072 = 10                (drilling feed)
#1073 = 40                (milling down feed)
(--------------------)
(Startup)
G90                       (absolute coordinates)
G21                       (METRIC units)
(--------------------)
(Center of near edge is origin point)
M05                       (spindle off)
(msg,Verify origin at center of near edge, then hit [Resume])
M00                       (wait for resume)
(--------------------)
(Mill the perimeter)
G0 Z#1003                 (get air)
G0 X#1001 Y#1002 (tool change)
(msg,Install 1/4" mill, then hit [Resume])
M00                       (wait for resume)
(msg, Set 1500 RPM, then hit [Resume])
M00                       (Wait for Resume)
M03                       (Spindle CW)
#995 = [[0 - #1013] / 5]  (depth per pass)
#999 = 0                          (starting depth)
(- turn on cutter compensation)
G0  X-10 Y-15                     (compensation alignment
point)
G0  Z#999                         (to surface for first pass)
G42 D4 G1 X-10 Y-10 F#1071        (compensation alignment
move, cutter right)
G2  X0 Y0 I10 J0         (compensation entry arc to mid front
side)
(- 0 pass)
G1  X#2011 Y#2012 F#1071    (R near corner entry)
G3  X#2013 Y#2014 R#2015    (R near corner arc)
G3  X#2041 Y#2042 R#2003    (R side arc)
G3  X#2043 Y#2044 R#1027   (R far corner arc)
G3  X[0 - #2043] Y#2044 R#2004    (far side arc)
G3  X[0 - #2041] Y#2042 R#1027    (L far corner arc)
G3  X[0 - #2013] Y#2014 R#2003    (L side arc)
G3  X[0 - #2011] Y#2012 R#2015    (L near corner arc)
G1  X0 Y0                         (return to mid front side)
(- 1 pass)
#999 = [#999 - #995]              (step down)
G1  Z#999 F#1073         ( to new depth)
G1  X#2011 Y#2012 F#1071    (R near corner entry)
G3  X#2013 Y#2014 R#2015    (R near corner arc)
G3  X#2041 Y#2042 R#2003    (R side arc)
G3  X#2043 Y#2044 R#1027   (R far corner arc)
G3  X[0 - #2043] Y#2044 R#2004    (far side arc)
G3  X[0 - #2041] Y#2042 R#1027    (L far corner arc)
G3  X[0 - #2013] Y#2014 R#2003    (L side arc)
G3  X[0 - #2011] Y#2012 R#2015    (L near corner arc)
G1  X0 Y0                         (return to mid front side)
(- 2 pass)
#999 = [#999 - #995]              (step down)
G1  Z#999 F#1073         ( to new depth)
G1  X#2011 Y#2012 F#1071    (R near corner entry)
G3  X#2013 Y#2014 R#2015    (R near corner arc)
G3  X#2041 Y#2042 R#2003    (R side arc)
G3  X#2043 Y#2044 R#1027   (R far corner arc)
G3  X[0 - #2043] Y#2044 R#2004    (far side arc)
G3  X[0 - #2041] Y#2042 R#1027    (L far corner arc)
G3  X[0 - #2013] Y#2014 R#2003    (L side arc)
G3  X[0 - #2011] Y#2012 R#2015    (L near corner arc)
G1  X0 Y0                         (return to mid front side)
(- 3 pass)
#999 = [#999 - #995]              (step down)
G1  Z#999 F#1073         ( to new depth)
G1  X#2011 Y#2012 F#1071    (R near corner entry)
G3  X#2013 Y#2014 R#2015    (R near corner arc)
G3  X#2041 Y#2042 R#2003    (R side arc)
G3  X#2043 Y#2044 R#1027   (R far corner arc)
G3  X[0 - #2043] Y#2044 R#2004    (far side arc)
G3  X[0 - #2041] Y#2042 R#1027    (L far corner arc)
G3  X[0 - #2013] Y#2014 R#2003    (L side arc)
G3  X[0 - #2011] Y#2012 R#2015    (L near corner arc)
G1  X0 Y0                         (return to mid front side)
(- 4 pass)
#999 = [#999 - #995]              (step down)
G1  Z#999 F#1073         ( to new depth)
G1  X#2011 Y#2012 F#1071    (R near corner entry)
G3  X#2013 Y#2014 R#2015    (R near corner arc)
G3  X#2041 Y#2042 R#2003    (R side arc)
G3  X#2043 Y#2044 R#1027   (R far corner arc)
G3  X[0 - #2043] Y#2044 R#2004    (far side arc)
G3  X[0 - #2041] Y#2042 R#1027    (L far corner arc)
G3  X[0 - #2013] Y#2014 R#2003    (L side arc)
G3  X[0 - #2011] Y#2012 R#2015    (L near corner arc)
G1  X0 Y0                         (return to mid front side)
(- 5 pass)
#999 = [#999 - #995]              (step down)
G1  Z#999 F#1073         ( to new depth)
G1  X#2011 Y#2012 F#1071    (R near corner entry)
G3  X#2013 Y#2014 R#2015    (R near corner arc)
G3  X#2041 Y#2042 R#2003    (R side arc)
G3  X#2043 Y#2044 R#1027   (R far corner arc)
G3  X[0 - #2043] Y#2044 R#2004    (far side arc)
G3  X[0 - #2041] Y#2042 R#1027    (L far corner arc)
G3  X[0 - #2013] Y#2014 R#2003    (L side arc)
G3  X[0 - #2011] Y#2012 R#2015    (L near corner arc)
G1  X0 Y0                         (return to mid front side)
(--------------------)
(Done!)
M05                      (spindle off)
G0  Z#1003               (get big air)
G0  X#1001 Y#1002        (tool change)
(msg,Done!)
M30
%
```

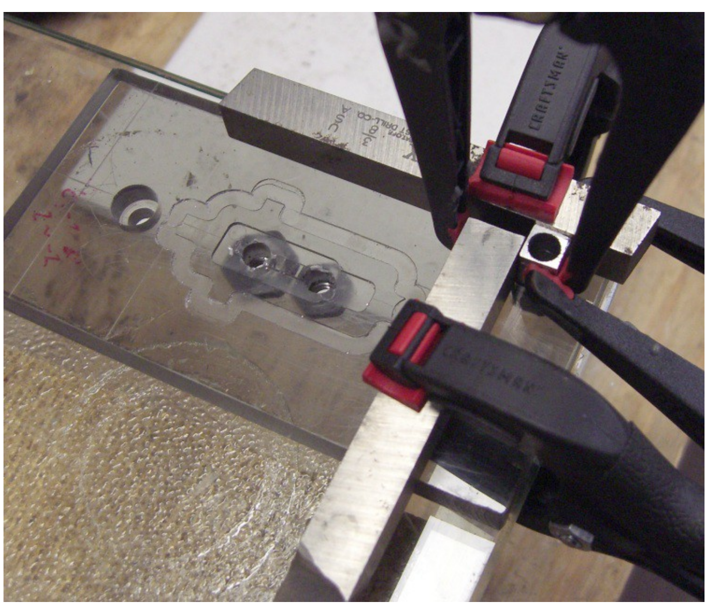
Door Latch Cam

Duplicating a worn cam for our storm door latch. I drilled & filed the square hole: I need a broach!

This old code would be much smaller and easier to read with the new EMC2 G-Code language features.

The ridges in the middle cam revealed an EMC bug!

```
%
( Storm door latch cam )
( Outside milling, clamped on center axis)
( Ed Nisley - Nov 2006 - Mar 2007)
(-----------------)
#1000 =  -50.00                (tool change XYZ)
#1001 =  -20.00
#1002 =  75.00
#1004 =  10.00                 (traverse clearance)

(-----------------)
(Cutter and material values)

#1110 =   3.10                 (cutter diameter)
#1111 = [0.0005 * 25.4]        (chip load, inches/tooth -> mm/tooth)
#1112 =   2                    (number of teeth)
#1113 =   1                    (tool slot holding this cutter)
#1114 =  1.00                  (max cut depth)
#1115 =  1.00                  (max cut width)

#1120 = [150 * 12 * 25.4]      (cutting speed, surface ft/min > mm/min)
#1121 = [#1120 / [3.14 * #1110]]          (spindle RPM)
#1122 = [#1121 * #1111 * #1112]           (milling feed, mm/min = RPM *
load * teeth)
```



```
(-----------------)
(Part dimensions)

#1201 =  4.17                  (shaft Z thickness)
#1202 =  2.95                  (cam Z thickness)

#1211 = FUP[#1201 / #1114]     (shaft Z passes)
#1212 = FUP[#1202 / #1114]     (cam Z passes)

#1221 = [#1201 / #1211]        (shaft Z cut depth)
#1222 = [#1202 / #1212]        (cam Z cut depth)

#1230 = [17.75 / 2]            (raw part OD -> radius)
#1231 = [10.30 / 2]            (shaft finished OD and cam small OD)
#1232 = [17.36 / 2]            (cam large OD)

#1241 = FUP[[#1230 - #1231] / #1115]    (shaft radius passes)
#1242 = FUP[[#1230 - #1232] / #1115]    (cam OD radius passes)

#1251 = [[#1230 - #1231] / #1241]       (shaft radius cut depth)
#1252 = [[#1230 - #1232] / #1242]       (cam OD radius cut depth)

#1272 = [216 / 2]                       (half-angle of cam solid arc)

#1300 =  1.60        (inside corner fillet radius = min arc turn radius)

(-----------------)
(Define setup)

G90 G21                        (absolute metric)
S #1121 F #1122                (set spindle & milling speeds)
T #1113 M6                     (set up the tool)

(-----------------)
(msg,Verify METRIC Sherline.tbl file!)
(msg,Align XY=0 at center, Z=0 at surface, spindle to match S value, hit
[Run])

M0                                      (wait for Resume)
M3                                      (spindle CW)
G0 Z#1004            (get air for alignment)

(-----------------)
(Commence cutting!)
(Start cutter compensation)
(External cutting: CCW around the part)
```

```
G0 X[0-#1300] Y[0-[#1230 + 3 * #1300]]  (alignment move)
G42 D#1113                    (comp on: tool to right, D = cutter)
G1 X[0-#1300] Y[0-[#1230 + #1300]]      (first entry move)
G2 X0 Y[0-#1230] I#1300 J0              (second entry move to part edge)

G0 Z#1004                     (to traverse level)

(--- Cut shaft)

O309 IF [1]

#900 = 0                      (Z iteration counter - start at surface)
#901 = 0.00                   (initial Z cut depth)

O300 DO                       (Z iteration)

G1 Z#901                      (to new Z level)

#910 = 0                      (radius iteration counter)
#911 = #1230                  (initial radius - start at raw OD)

O310 DO                       (radius iteration)

O311 IF [#911 NE #1230]       (if new is not max OD, then reposition)
G91                           (relative coords)
G2 Y[0 - 2 * #1300] J[0-#1300]          (loop outward by min radius)
G2 Y[#1251 + 2 * #1300] J[#1300 + #1251 / 2] (loop inward to new radius)
G90                           (abs coords)
O311 ENDIF

G3 Y[0-#911] J[#911]          (one pass CCW around shaft)

#910 = [#910 + 1]             (tick radius counter)
#911 = [#911 - #1251]         (figure next radius)

O310 WHILE [#910 LE #1241]    (for all radius passes)

G2 Y[0 -[#1230 + 2 * #1300]] J[0 -[[[#1230 - #1231] / 2] + #1300]]
(finish OD -> max OD)
G2 Y[0 -#1230] J[#1300]

#900 = [#900 + 1]             (tick loop counter)
#901 = [#901 - #1221]         (next Z level)

O300 WHILE [#900 LE #1211]    (for all Z steps)

O309 ENDIF

(--- Cut cam OD)

O349 IF [1]

#900 = 0            (Z iteration counter - at top of cam)
#901 = [0-#1201]    (initial Z cut depth - top of cam = bottom of shaft)

O340 DO             (Z iteration)

G1 Z#901            (to new Z level)

#910 = 0            (radius iteration counter)
#911 = #1230                  (initial radius - start at raw OD)

O350 DO                       (radius iteration)

O351 IF [#911 NE #1230]       (if new is not max OD, then reposition)
G91                           (relative coords)
G2 Y[0 - 2 * #1300] J[0-#1300]          (loop outward by min radius)
G2 Y[#1252 + 2 * #1300] J[#1300 + #1252 / 2]      (loop in to new radius)
G90                           (abs coords)
O351 ENDIF

G3 Y[0-#911] J[#911]          (one pass CCW around shaft)

#910 = [#910 + 1]             (tick radius counter)
#911 = [#911 - #1252]         (figure next radius)

O350 WHILE [#910 LE #1242]    (for all radius passes)

G2 Y[0 -[#1230 + 2 * #1300]] J[0 -[[[#1230 - #1232] / 2] + #1300]]
(finish OD -> max OD)
G2 Y[0 -#1230] J[#1300]

#900 = [#900 + 1]             (tick loop counter)
#901 = [#901 - #1222]         (next Z level)

O340 WHILE [#900 LE #1212]    (for all Z steps)

O349 ENDIF

(--- Cut cam ID)
(This goes in to shaft OD)
(Realign for CW passes in air clearing max OD by a bit, CCW cutting)

O389 IF [1]

G0 Z#1004           (reposition at clearance OD facing CW for next move)

#520 = [#1110 + 2 * #1300]    (cutter dia + 2 x min fillet radius)
#521 = [#1230 + #520]         ("exterior material contour" for air cut)

G2 Y[0 -#521] J[0 -[#520 / 2]] (half-circle to new OD, cutter still to
right)

#522 = [#521 - #1300]         (O-P - dist origin to outer circle center)
#523 = [ASIN[#1300 / #522]]   (alpha - angle cam edge to outer cir ctr)
#524 = [#1272 - #523]         (beta - angle Y axis to outer cir center)
#525 = [#522 * COS[#523]]     (O-B - dist origin to B tan on cam edge)

#531 = [#521 * SIN[#524]]     (A - X coord fairing circle tangent to OD)
#532 = [#521 * COS[#524]]     (A - Y coord fairing circle tangent to OD)

#541 = [#525 * SIN[#1272]]    (B - X coord fairing circle tangent to cam)
#542 = [#525 * COS[#1272]]    (B - Y coord fairing circle tangent to cam)

#551 = [#522 * SIN[#524]]     (P - X coord fairing circle center)
#552 = [#522 * COS[#524]]     (P - Y coord fairing circle center)

#900 = 0            (Z iteration counter - start at top of cam again)
#901 = [0 -#1201]   (initial Z cut level - top of cam = bottom of shaft)

O380 DO                       (Z iteration)

G1 Z#901                      (to new Z level)

#910 = 0                      (radius iteration counter)
#911 = #1230                  (initial radius - start at raw OD)

O390 DO                       (radius iteration)

#622 = [#911 + #1300] (O-Q - dist orgin to current inner circle center)
#623 = [ASIN[#1300 / #622]] (gamma - angle cam edge to inner cir ctr)
#624 = [#1272 - #623] (delta - angle Y axis to inner circle center)
#625 = [#622 * COS[#623]] (O-C - dist origin to C tangent on cam edge)

#631 = [#625 * SIN[#1272]]    (C - X coord inner circle tangent to cam)
#632 = [#625 * COS[#1272]]    (C - Y coord inner circle tangent to cam)

#641 = [#911 * SIN[#624]]     (D - X coord inner circle tangent to shaft)
#642 = [#911 * COS[#624]]     (D - Y coord inner circle tangent to shaft)

#651 = [#622 * SIN[#624]]     (Q - X coord inner circle center)
#652 = [#622 * COS[#624]]     (Q - Y coord inner circle center)

G2 X[0 -#531] Y[0 -#532] J[#521]        (left side of air pass)
G2 X[0 -#541] Y[0 -#542] I[#531 - #551] J[#532 - #552]
(fillet to cam edge)

G1 X[0 -#631] Y[0 -#632]      (left cam edge)
G2 X[0 -#641] Y[0 -#642] I[#631 - #651] J[#632 - #652]
(fillet to current shaft OD)

G3 X[#641] Y[0 -#642] I[#641] J[#642]             (current shaft OD)
G2 X[#631] Y[0 -#632] I[#651 - #641] J[#642 - #652]
          (fillet to cam edge)

G1 X[#541] Y[0 -#542]                   (right cam edge)
G2 X[#531] Y[0 -#532] I[#551 - #541] J[#542 - #552]
          (fillet to air pass)

G2 X[0] Y[0 -#521] I[0 -#531] J[#532]   (right side of air pass)

#910 = [#910 + 1]                       (tick radius counter)
#911 = [#911 - #1251]                   (figure next radius)

O390 WHILE [#910 LE #1241]    (for all radius passes)

#900 = [#900 + 1]             (tick loop counter)
#901 = [#901 - #1222]         (next Z level)

O380 WHILE [#900 LE #1212]    (for all Z steps)

O389 ENDIF

(-----------------)
M5                            (spindle off)
G0 Z#1002                     (get air)

G40                           (cutter comp off)

G0 X#1000 Y#1001    (return home)
(msg,Done!)
M2
%
```

Anti-Snoring Nose Strips

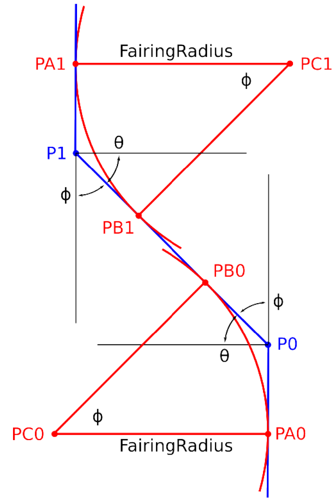
A rumor from a reliable source has it that I snore; I can't imagine that, but so I'm told. After trying this and that, Breathe-Right Nasal Strips were helpful. The general idea is that a spring taped across your nose provides a wider aperture and encourages you to breathe through your nose, rather than your mouth. However, 30 cents a night didn't sit well with our family CFO.

Ordinary consumer packaging provides thin polypropylene sheets with the right springiness. 3M Nexcare Gentle Paper Tape actually sticks to a nose overnight. CNC makes cutting out a bunch of springs a simple matter of software, particularly using EMC2's named parameters.

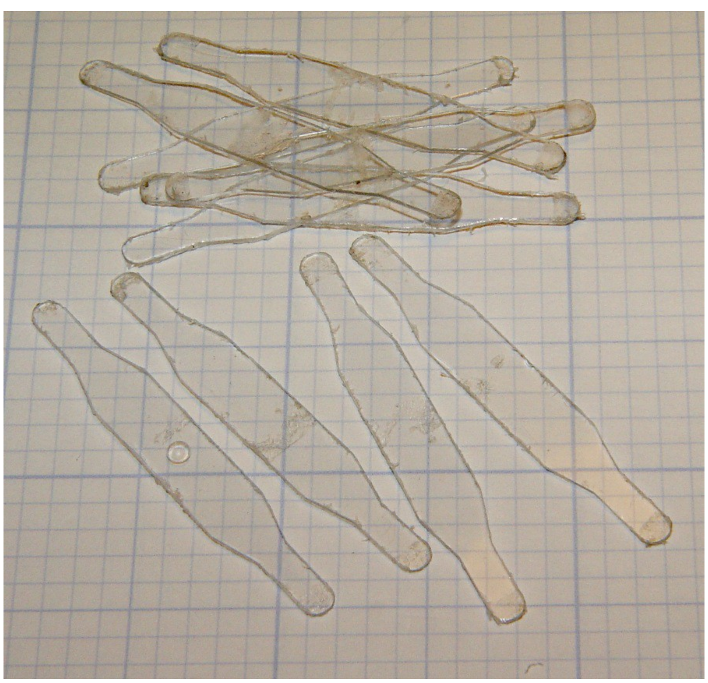
The diagrams show how to figure the smooth fairing arcs that joining the two straight sections. EMC2 will automatically insert fairing arcs, but it uses the absolute minimum possible radius, rather than something that looks good. All four arcs are identical to simplify the code and simple semicircular arcs finish the ends of the spring.

The widths of the straight sections determine the X coordinates. The lengths of those sections determine the Y coordinates for the arc centers. Knowing those values, plus the arc radius, you can find the arc center point coordinates. Then a bit of trigonometry provides the coordinates of the tangent points on the line between the straight sections; you could do it with linear interpolation, but I think trig gives a cleaner solution.

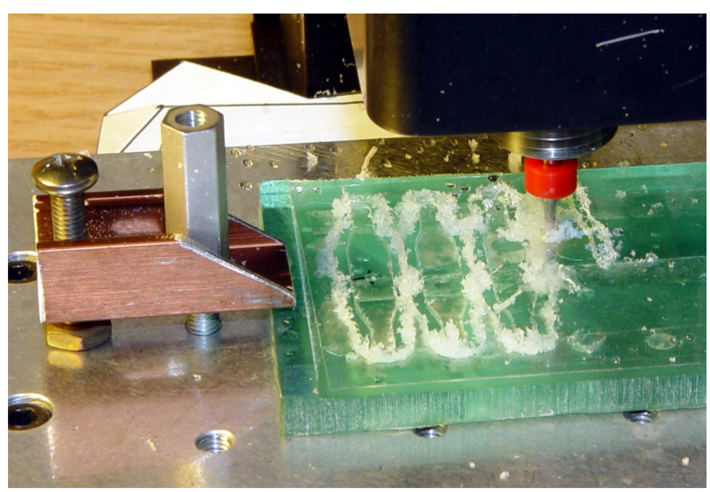
The picture of the milling operation shows that the polypropylene doesn't machine well at all, even with water to



keeping the plastic cool. At least it didn't fuse into a gummy mass around the end mill!



```
%
(Ersatz Breathe-Right Nasal Strips)
(Parts repeated along X axis, long side parallel to Y)
(Taped flat to sacrificial baseplate)
(Origin at center of leftmost piece, Z=0 at substrate)

(-- Tool change position)

#5161 =   0                         (X)
#5162 =   0                         (Y)
#5163 =   [50.8 / 25.4]             (Z)

(-- Z Positions)

#<_Traverse_Z>    =  2.0            (Z traverse clearance)
#<_Cut_Z>         = -0.2            (Z cut depth)

(-- Part dimensions)

#<_NumParts>      = 10              (number of parts to cut)
#<_PartSpacing_X> = 10.0  (part spacing on center)

#<_OverallLength> = 40.0  (overall length)

#<_BodyLength>    =  16.0           (center body length)
#<_BodyWidth>     =  6.0            (center body width)

#<_TongueLength> = 7.0              (tongue length)
```



```
#<_TongueWidth>  =  3.0          (tongue width)

#<_Tool_Dia>     = 2.0           (tool dia)
#<_Tool_Slot>    = 1                     (tool slot)

(-- Compute part values)

#<_BodyLength_Half>      = [#<_BodyLength> / 2]

#<_Tongue_Radius>        = [#<_TongueWidth> / 2]
#<_Tongue_Straight_Length> = [#<_TongueLength> -
#<_Tongue_Radius>]

#<_TaperLength>          = [#<_OverallLength> / 2 -
#<_BodyLength_Half> - #<_TongueLength>]
#<_TaperWidth>           = [#<_BodyWidth> / 2 -
#<_TongueWidth> / 2]

(-- Compute fairing values)

#<_Fairing_Radius> = [1.1 * #<_Tool_Dia> / 2]      (slightly
larger than tool radius)

#<_Phi>  = ATAN [#<_TaperWidth>] / [#<_TaperLength>] (from Y
axis)
#<_Theta> = [90 - #<_Phi>]       (from X axis)

#<_CBx> = [#<_Fairing_Radius> * COS [#<_Phi>]] (X distance PC
to PB)
#<_CBy> = [#<_Fairing_Radius> * SIN [#<_Phi>]] (Y ...)

#<_P0PBx> = [#<_Fairing_Radius> * [1 - COS [#<_Phi>]]] (X
distance P0 to PB)
#<_P0PBy> = [#<_P0PBx> * TAN [#<_Theta>]]  (Y ...)

#<_P0PAx> = 0                    (X distance P0 to PA)
#<_P0PAy> = [#<_CBy> - #<_P0PBy>] (Y ...)

#<_Fairing_X> = [#<_P0PBx>]      (X extent of fairing arc)
#<_Fairing_Y> = [#<_P0PAy> + #<_P0PBy>]   (Y ...)

#<_BodySide> = [#<_BodyLength_Half> - #<_P0PAy>] (body length
- ctr to fairing)
#<_TongueSide> = [#<_Tongue_Straight_Length> - #<_P0PAy>]
(tongue length - cap to fairing)

#<_Taper_Faired_X> = [#<_TaperWidth> - 2 * [#<_Fairing_X>]] (X
extent of faired taper)
#<_Taper_Faired_Y> = [#<_TaperLength> - 2 * [#<_P0PBy>]     (Y
...)

(-- Speeds & Feeds)

#<_Mill_RPM>     = 3000  (milling RPM)
#<_Mill_Feed>    = 150   (milling feed)
#<_Traverse_Feed> = 500  (traverse speed - no contact!)

(----- Start cutting)

G90                      (absolute coordinates)
G21                      (METRIC units)
M5                       (spindle off)
G0 X0 Y0 Z0              (home)

(msg,Verify origin = center of left part, Z=0 at sacrificial
plate)
M0                       (wait for resume)
G0 Z#5163                (get air, then to tool change)
G28
T #<_Tool_Slot> M6       (fake tool change for Axis backplot)

(debug,Insert #<_Tool_Dia> mm end mill, set #<_Mill_RPM> RPM,
hit Resume)
M0                       (wait for resume)
M3                       (spindle CW)

(-- Crank them out)

#<_PartNum> = 0                  (part index along X)

O100 DO

#<_PartCenter_X> = [#<_PartNum> * #<_PartSpacing_X>] (X center
coordinate)

G0 X[#<_PartCenter_X> - #<_BodyWidth> / 2] Y0  (go to left
side of part)
G0 Z#<_Traverse_Z>

G10 L2 P2 X#<_PartCenter_X> (set coord sys 2 to current part)
G55                      (select coord sys 2)

G42.1 D#<_Tool_Dia>      (cutter comp on right)
G3 X[#<_BodyWidth> / 2] I[#<_BodyWidth> / 2]
F#<_Traverse_Feed>       (CCW entry arc to right side)

G1 Z#<_Cut_Z> F#<_Mill_Feed> (punch to cut depth, set feed)

G91                      (incremental mode)

G1 Y[#<_BodySide>]       (upper right body)

G3 X[0 - #<_Fairing_X>] Y[#<_Fairing_Y>] I[0 -
#<_Fairing_Radius>]      (fairing convex to taper)
G1 X[0 - #<_Taper_Faired_X>] Y[#<_Taper_Faired_Y>] (taper
straight)
G2 X[0 - #<_Fairing_X>] Y[#<_Fairing_Y>] I[#<_CBx>] J[#<_CBy>]
(fairing concave to tongue)

G1 Y[#<_Tongue_Straight_Length>]  (tongue right)

G3 X[0 - #<_TongueWidth>] I[0 - #<_Tongue_Radius>] (end cap)

G1 Y[0 - #<_Tongue_Straight_Length>]      (tongue left)
G2 X[0 - #<_Fairing_X>] Y[0 - #<_Fairing_Y>] I[0 - #<_CBx>]
       (fairing concave to taper)
G1 X[0 - #<_Taper_Faired_X>] Y[0 - #<_Taper_Faired_Y>]
       (taper straight)
G3 X[0 - #<_Fairing_X>] Y[0 - #<_Fairing_Y>] I[#<_CBx>] J[0 -
#<_CBy>]         (fairing convex to body)

G1 Y[0 - 2 * #<_BodySide>]                (left side)

G3 X[#<_Fairing_X>] Y[0 - #<_Fairing_Y>] I[#<_Fairing_Radius>]
       (fairing convex to taper)
G1 X[#<_Taper_Faired_X>] Y[0 - #<_Taper_Faired_Y>] (taper
straight)
G2 X[#<_Fairing_X>] Y[0 - #<_Fairing_Y>] I[0 - #<_CBx>] J[0 -
#<_CBy>]         (fairing concave to tongue)
G1 Y[0 - #<_Tongue_Straight_Length>]      (tongue left)

G3 X[#<_TongueWidth>] I[#<_Tongue_Radius>] (end cap)

G1 Y[#<_Tongue_Straight_Length>]          (tongue right)
G2 X[#<_Fairing_X>] Y[#<_Fairing_Y>] I[#<_CBx>]    (fairing
concave to taper)
G1 X[#<_Taper_Faired_X>] Y[#<_Taper_Faired_Y>]     (taper
straight)
G3 X[#<_Fairing_X>] Y[#<_Fairing_Y>] I[0 - #<_CBx>] J[#<_CBy>]
       (fairing convex to body)

G1 Y[#<_BodyLength>]             (clear entire right side)

G90                              (absolute mode)

G0 Z#<_Traverse_Z>               (get air)

G40                              (cutter comp off)
G54                              (coord sys 1 again)

#<_PartNum> = [#<_PartNum> + 1]   (tick X index)
O100 WHILE [#<_PartNum> LT #<_NumParts>]

(-- cleanup)

M5                       (spindle off)
G0 Z [#5163 * 25.4]      (get air, then to tool change)
G28

M30
%
```

Dog Tags

My father's WWII tag provided the outline and dimensions for these tags, including the mysterious notch. The rounded ends have three blended curves: two small fairing arcs blend the sides into the end cap.

The G-Code routine figures out all the coordinates and angles from a few physical measurements, which means you can tweak the size by changing meaningful numbers.

My Shop Assistant fired up Inkscape, laid out the text using the center of the chain hole as the coordinate origin, then figured out how to coerce G-Code out of Inkscape using the cnc-club.ru extension. My main routine calls that G-Code file as a subroutine to engrave the text.

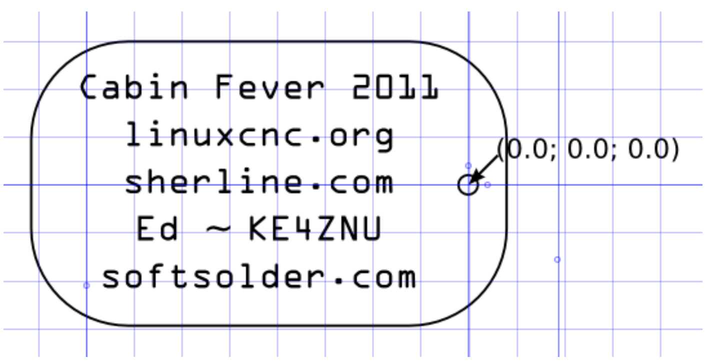
The Inkscape extension produces G-Code commands with absolute coordinates using the origin you define when you create the layout. The nested loops in my program slap a G55 coordinate offset atop each label in turn, so the subroutine works without changes at each tag position.

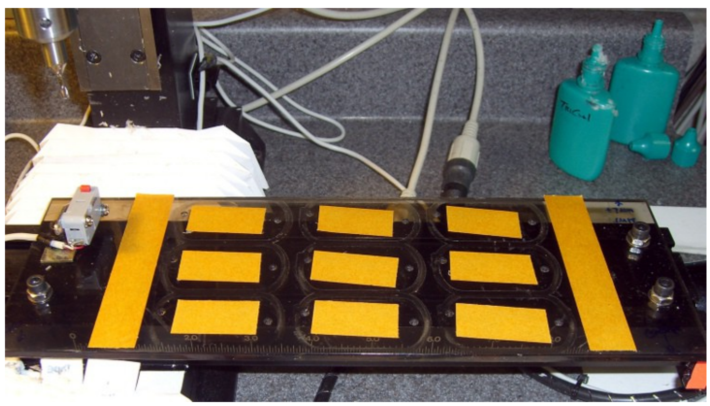
We then added subroutine calls to engrave different names on each tag; my Assistant passed out personalized tags at her birthday party. The background and name layouts must fit together; the whole lashup is a kludge, but sufficient for this purpose.

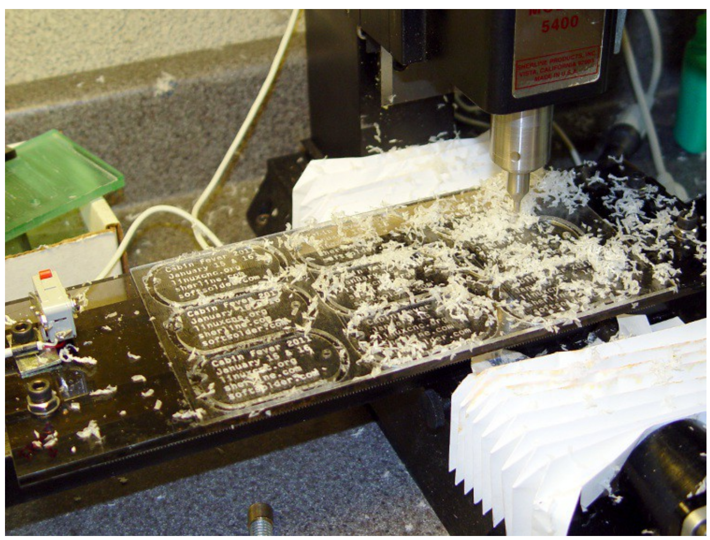
Strips of tapeless sticky (adhesive without tape!) hold the acrylic sheet to the platen for engraving, drilling, and milling. Finger-rubbing and xylene remove the adhesive. Keep the adhesive away from the tag perimeter, because it gums up the end mill something awful!

The gray switch on the far left end of the platen measures the tool length after each change. I zero the first tool at the material surface and the G-Code automatically adjusts all the others!

```
(Cabin Fever 2011 Dogtag Cutout)
(Ed Nisley - KE4ZNU - softsolder.com)
(Origin at center of chain hole near right side)
(Stock held down with double-stick tape)

(--------------------)
(Flow Control)

#<_DoText>      = 1
#<_DoDrill>     = 1
#<_DoMill>      = 1

( Sizes and Shapes)

(-- Tag array layout)

#<_NumTagsX>    = 3       (number of tags along X axis)
#<_NumTagsY>    = 3       ( ... Y axis)

#<_TagBase>     = -1      (starting tag number, -1 to disable)
```



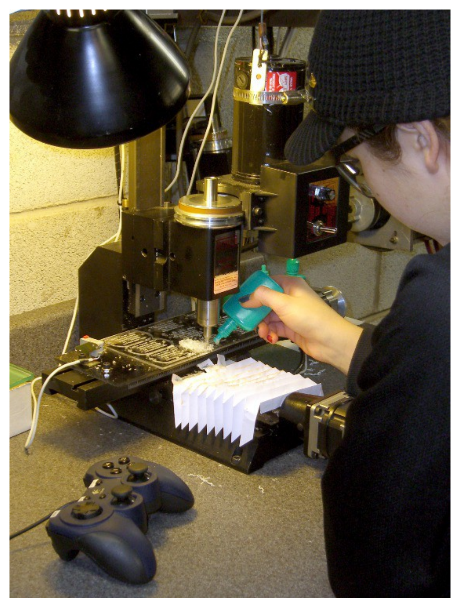




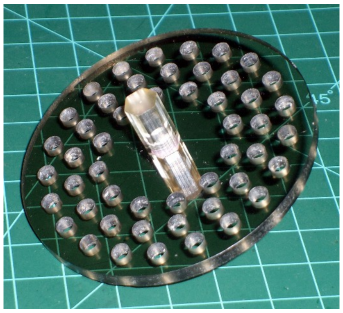
```
#<_TagSpaceX>   = 60      (center-to-center along X axis)
#<_TagSpaceY>   = 33      ( ... Y axis)

(-- Tag Dimensions)

#<_TagSizeX>    = 50.8    (2.0 inches in WWII!)
#<_TagSizeY>    = 28.6    (1-1/8 inches)
#<_TagSizeZ>    = 2.45    (sheet thickness)

#<_HoleOffsetX> = 4.0      (hole ctr to right-side tag edge)

#<_NotchSizeX>      = 3.5 (locating notch depth from far left
edge)
#<_NotchCtrY>       = 5.0 (locating notch from Y=0)

#<_NotchAngleBot>   = 30   (lower angle in notch)
#<_NotchAngleTop>   = 45   (upper angle in notch)

(-- Fairing Curve Dimensions as offsets from end arc center)

#<_EndFairR>    = [0.68 * #<_TagSizeY>]
#<_CornerFairR> = [0.25 * #<_TagSizeY>]

#<_PCRadius>    = [#<_EndFairR> - #<_CornerFairR>]
#<_PCY>         = [[#<_TagSizeY> / 2] - #<_CornerFairR>]
#<_PCTheta>     = ASIN [#<_PCY> / #<_PCRadius>]
#<_PCX>         = [#<_PCRadius> * COS [#<_PCTheta>]]

#<_P1Y>         = [#<_TagSizeY> / 2]        (top/bot endpoint)
#<_P1X>         = #<_PCX>

#<_P2X>         = [#<_EndFairR> * COS [#<_PCTheta>]]
#<_P2Y>         = [#<_EndFairR> * SIN [#<_PCTheta>]]

(-- Tooling)

#<_TraverseZ>   = 1.0      (safe clearance above workpiece)

#<_TextDia>     = 0.1      (engraving tool)
#<_TextNum>     = 1
#<_TextFeed>    = 600      (tool feed for engraving)
#<_TextRPM>     = 3000

#<_DrillDia>    = 3.2      (drill for hole and notch)
#<_DrillNum>    = 1       ( ... tool number)
#<_DrillRadius> = [#<_DrillDia> / 2]
#<_DrillFeed>   = 200      (drill feed for holes)
#<_DrillRPM>    = 3000

#<_MillDia>     = 3.2      (mill for outline)
#<_MillNum>     = 1       ( ... tool number)
#<_MillRadius> = [#<_MillDia> / 2]
#<_MillFeed>    = 200      (tool feed for outlines)
#<_MillRPM>     = 3000

(-- Useful calculated values)

#<_TagRightX>   = #<_HoleOffsetX> (extreme limits of tag in X)
#<_TagLeftX>    = [#<_TagRightX> - #<_TagSizeX>]

#<_EndFairRtX>  = [#<_TagRightX> - #<_EndFairR>]
#<_EndFairLfX>  = [#<_TagLeftX> + #<_EndFairR>]

#<_NotchCtrX>   = [#<_TagLeftX> + #<_NotchSizeX> -
#<_DrillRadius>]

(--------------------)
( Initialize first tool length at probe switch)
(    Assumes G59.3 is still in machine units, returns in G54)
( ** Must set these constants to match G20 / G21 condition!)

#<_Probe_Speed>     = 400         (set for mm or inch)
#<_Probe_Retract>   =   1         (ditto)

O<Probe_Tool> SUB

G49       (clear tool length compensation)
G30       (move above probe switch)
G59.3   (coord system 9)

G38.2 Z0 F#<_Probe_Speed> (trip switch on the way down)

G0 Z[#5063 + #<_Probe_Retract>]     (back off the switch)

G38.2 Z0 F[#<_Probe_Speed> / 10]    (trip switch slowly)

#<_ToolZ> = #5063         (save new tool length)

G43.1 Z[#<_ToolZ> - #<_ToolRefZ>]    (set new length)

G54       (coord system 0)
G30       (return to safe level)

O<Probe_Tool> ENDSUB

(-------------------)
(-- Initialize first tool length at probe switch)

O<Probe_Init> SUB

#<_ToolRefZ> = 0.0      (set up for first call)

O<Probe_Tool> CALL

#<_ToolRefZ> = #5063    (save trip point)

G43.1 Z0              (tool entered at Z=0, so set it there)

O<Probe_Init> ENDSUB

(--------------------)
(--------------------)
(Start machining)

G40 G49 G54 G80 G90 G94 G97 G98     (reset many things)

G21             (metric!)

(msg,Verify G30.1 position in G54 above tool change switch)
M0
(msg,Verify XYZ=0 at left front tag hole center on surface)
M0

O<Probe_Init> CALL
T0 M6     (clear the probe tool)


(-- Engrave Text)
(   Calls O<dogtagtext> file for each tag)
(   Also calls files #TagBase + 0, 1, 2, 3, ...)
(   All subroutine files used in the loop must exist!)

O<DoText> IF [#<_DoText>]

(msg,Insert engraving tool)
T#<_TextNum> M6         (load engraving tool)
O<Probe_Tool> CALL

F#<_TextFeed>
S#<_TextRPM>

(debug,Set spindle to #<_TextRPM>)
M0

G0 X0 Y0              (get safely to first tag)
G0 Z#<_TraverseZ>     (to working level)

G10 L20 P2 X0 Y0 Z#<_TraverseZ>   (set G55 origin to 0,0 here)
G55                 (activate G55 coordinates)

#<TagNum> = #<_TagBase>

O3000 REPEAT [#<_NumTagsX>]

O3100 REPEAT [#<_NumTagsY>]

O<dogtagtext> CALL

O3200 IF [#<_TagBase> GE 0]
O#<TagNum> CALL
O3200 ENDIF
```

```
#<TagNum> = [#<TagNum> + 1]

G0 X0 Y0
G10 L20 P2 Y[0 - #<_TagSpaceY>]   (set Y orig to next tag +Y)

O3100 ENDREPEAT

G10 L20 P2 X[0 - #<_TagSpaceX>] Y[[#<_NumTagsY> - 1] *
#<_TagSpaceY>] (next to +X, Y to front)

O3000 ENDREPEAT

G54                  (bail out of G55 coordinates)


(-- Drill holes)

O<DoDrill> IF [#<_DoDrill>]

T0 M6
(msg,Insert drill)
T#<_DrillNum> M6
O<Probe_Tool> CALL

F#<_DrillFeed>
S#<_DrillRPM>

#<_DrillZ> = [0 - #<_TagSizeZ> - #<_DrillRadius>]

(debug,Set spindle to #<_DrillRPM>)
M0

G0 X0 Y0                (get safely to first tag)
G0 Z#<_TraverseZ>       (to working level)

#<IndexX> = 0
O1000 DO

#<IndexY> = 0
O1100 DO

#<TagOriginX> = [#<IndexX> * #<_TagSpaceX>]
#<TagOriginY> = [#<IndexY> * #<_TagSpaceY>]

G81 X#<TagOriginX> Y#<TagOriginY> Z#<_DrillZ> R#<_TraverseZ>
G81 X[#<TagOriginX> + #<_NotchCtrX>] Y[#<TagOriginY> +
#<_NotchCtrY>] Z#<_DrillZ> R#<_TraverseZ>

#<IndexY> = [#<IndexY> + 1]
O1100 WHILE [#<IndexY> LT #<_NumTagsY>]

#<IndexX> = [#<IndexX> + 1]
O1000 WHILE [#<IndexX> LT #<_NumTagsX>]

G30     (go home)

O<DoDrill> ENDIF

(-- Machine outlines)

O<DoMill> IF [#<_DoMill>]

T0 M6   (eject drill)
(msg,Insert end mill)
T#<_MillNum> M6         (load mill)
O<Probe_Tool> CALL

F#<_MillFeed>
S#<_MillRPM>

(debug,Set spindle to #<_MillRPM>)
M0

G0 X0 Y0                (get safely to first tag)
G0 Z#<_TraverseZ>       (to working level)

G10 L20 P2 X0 Y0 Z#<_TraverseZ>   (set G55 origin to 0,0 here)
G55                  (activate G55 coordinates)

O2000 REPEAT [#<_NumTagsX>]
```

```
O2100 REPEAT [#<_NumTagsY>]

G0 X[#<_NotchCtrX>] Y[#<_NotchCtrY>]       (get to notch ctr)
G0 Z[0 - #<_TagSizeZ>]    (down to cutting level)

G91      (relative coordinate for notch cutting)
G1 X[0 - #<_NotchSizeX>] Y[0 -  #<_NotchSizeX> * TAN
[#<_NotchAngleBot>]]
G1 X[0 + #<_NotchSizeX>] Y[0 +  #<_NotchSizeX> * TAN
[#<_NotchAngleBot>]]
G1 X[0 - #<_NotchSizeX>] Y[0 +  #<_NotchSizeX> * TAN
[#<_NotchAngleTop>]]
G90                        (back to abs coords)

G42.1 D#<_MillDia>         (cutter comp to right)
G1 X[#<_TagLeftX>] Y0      (comp entry to tip of left endcap)

G3 X[#<_EndFairLfX> - #<_P2X>] Y[0 - #<_P2Y>] I[#<_EndFairR>]
J0    (left endcap front half)

G3 X[#<_EndFairLfX> - #<_P1X>] Y[0 - #<_P1Y>] I[#<_P2X> -
#<_PCX>] J[#<_P2Y> - #<_PCY>]

G1 X[#<_EndFairRtX> + #<_P1X>]    (front edge)

G3 X[#<_EndFairRtX> + #<_P2X>] Y[0 - #<_P2Y>] I0
J[#<_CornerFairR>]

G3 X[#<_EndFairRtX> + #<_P2X>] Y[#<_P2Y>] I[0 - #<_P2X>]
J[#<_P2Y>]    (right endcap)

G3 X[#<_EndFairRtX> + #<_P1X>] Y[#<_P1Y>] I[#<_PCX> - #<_P2X>]
J[#<_PCY> - #<_P2Y>]

G1 X[#<_EndFairLfX> - #<_P1X>]    (rear edge)

G3 X[#<_EndFairLfX> - #<_P2X>] Y[#<_P2Y>] I0 J[0 -
#<_CornerFairR>]

G3 X[#<_EndFairLfX> - #<_P2X>] Y[0 - #<_P2Y>] I[#<_P2X>] J[0 -
#<_P2Y>]    (left endcap complete)

G0 Z#<_TraverseZ>

G40

G0 X0 Y0
G10 L20 P2 Y[0 - #<_TagSpaceY>]   (set Y org to next +Y tag)
O2100 ENDREPEAT

G10 L20 P2 X[0 - #<_TagSpaceX>] Y[[#<_NumTagsY> - 1] *
#<_TagSpaceY>] (next to +X, Y to front)

O2000 ENDREPEAT

G54      (bail out of
G55 coordinates)

G30         (go home)

O<DoMill> ENDIF

(msg,Done!)

M2
```



Sink Drain Strainer



A practical kitchen object built with EMC2's G-Code programming features!

A subroutine calculates the maximum number of holes at a specific diameter and finds their coordinates. The main program calls the subroutine three times to drill three rings of holes.

The milling code leaves three tabs holding the finished strainer to the surrounding stock, so there's no need to reclamp the part between the drilling and milling steps.

```
<<<<** This is an excerpt from the full program! **>>>>
(Drill & mill sink drain strainer)
(Ed Nisley KE4ZNU -- Digital Machinist 5.1 Spring 2010)

(----- Drill holes around circle)
(   Parameters: #1=Circle radius, #2=Hole dia, #3=Phase)
(        Phase = 0.0 - hole on +X axis)
(                1.0 - space on +X axis)

O9000 SUB

#<HoleWidthAngle> = [2 * ASIN [#2/[2 * #1]]]
(angle subtended by hole dia)
#<NumHoles>       = FIX[360 / [2 * #<HoleWidthAngle>]]
(integer number of holes + spaces)
#<HoleAngle>      = [360 / #<NumHoles>]
(angle between successive holes)

#<DrillAngle>     = [#3 * #<HoleAngle> / 2]         (starting
angle for drilling)

O9010 DO

#<HoleX>          = [#1 * COS[#<DrillAngle>]]
(find hole coordinates)
#<HoleY>          = [#1 * SIN[#<DrillAngle>]]
G81 X#<HoleX> Y#<HoleY> Z[0 - #<_DrillDepth>] R#<_TraverseZ>
F#<_DrillFeed>

#<DrillAngle>     = [#<DrillAngle> + #<HoleAngle>]   (step to
next hole)
O9010 WHILE [360 GT #<DrillAngle>]

O9000 ENDSUB

(------------------------)
(-- Drill hole circles)

O9000 CALL        [#<_Ring1Radius>] [#<_DrillDia>] [0.0]
O9000 CALL        [#<_Ring2Radius>] [#<_DrillDia>] [0.0]
O9000 CALL        [#<_Ring3Radius>] [#<_DrillDia>] [0.0]

G81 X0 Y0 Z[0 - #<_DrillDepth>] R#<_TraverseZ> F#<_DrillFeed>

(-- Mill outline)

G0 X[#<_OutsideRadius> + 2 * #<_MillDia>] Y0        (set up for
comp entry)
G42.1 D#<_MillDia>
G2 X#<_OutsideRadius> I[0 - #<_MillDia>] F#<_FeedTraverse>
(comp entry)

(-- Cut to top of tabs)

#<ZStep> = [#<_RampSlope> * #<_PI> * #<_OutsideDia>]
O200 IF  [#<ZStep> GT #<_MaxZCut>]
#<ZStep>          = #<_MaxZCut>
O200 ENDIF
```

```
#<CurrentZ>       = 0              (go to surface)
G0 Z#<CurrentZ>

#<TabZ>  = [0 - [#<_PlateSizeZ> - #<_TabThick>]]

O210 DO

#<CurrentZ>       = [#<CurrentZ> - #<ZStep>] (cut for pass)

O220 IF [#<CurrentZ> LT #<TabZ>]
#<CurrentZ>       = [#<TabZ>]       (stop at top of tabs)
O220 ENDIF

G3 I[0 - #<_OutsideRadius>] Z#<CurrentZ> F#<_MillSpeed>

O210 WHILE [#<CurrentZ> GT #<TabZ>]

G3 I[0 - #<_OutsideRadius>] (once more to clear final ramp)

(-- Cut around tabs through plate)
(    Start at top middle of the first tab!)

#<TabCenterAngle> = 0              (put first tab at angle = 0)
#<CurrentX> = #<_OutsideRadius>    (remember where we are)
#<CurrentY> = 0

#<TabCounter> = 0
O300 DO

#<ExitAngle> = [#<TabCenterAngle> + #<_TabHalfAngle> +
#<_MillHalfAngle>]
#<ExitX> = [#<_OutsideRadius> * COS [#<ExitAngle>]]
#<ExitY> = [#<_OutsideRadius> * SIN [#<ExitAngle>]]

G3 X#<ExitX> Y#<ExitY> I[0 - #<CurrentX>] J[0 - #<CurrentY>]
F#<_MillSpeed>    (move to end of tab)
G1 Z[0 - #<_PlateSizeZ>] F#<_MillFeed>     (punch thru plate)

#<CurrentX> = #<ExitX>             (remember where we are)
#<CurrentY> = #<ExitY>

#<TabCenterAngle> = [#<TabCenterAngle> + #<_TabSepAngle>]

#<EntryAngle> = [#<TabCenterAngle> - #<_TabHalfAngle> -
#<_MillHalfAngle>]
#<EntryX> = [#<_OutsideRadius> * COS [#<EntryAngle>]]
#<EntryY> = [#<_OutsideRadius> * SIN [#<EntryAngle>]]

G3 X#<EntryX> Y#<EntryY> I[0 - #<CurrentX>] J[0 - #<CurrentY>]
F#<_MillSpeed>    (cut to tab)
G0 Z[0 - [#<_PlateSizeZ> - #<_TabThick>]] (pop to tab top)

#<CurrentX> = #<EntryX>            (remember where we are)
#<CurrentY> = #<EntryY>

#<CenterX> = [#<_OutsideRadius> * COS [#<TabCenterAngle>]]
#<CenterY> = [#<_OutsideRadius> * SIN [#<TabCenterAngle>]]

G3 X#<CenterX> Y#<CenterY> I[0 - #<CurrentX>] J[0 -
#<CurrentY>] F#<_MillSpeed>       (to tab ctr)

#<CurrentX> = #<CenterX>           (remember where we are)
#<CurrentY> = #<CenterY>

#<TabCounter> = [1 + #<TabCounter>]
O300 WHILE [#<TabCounter> LT #<_NumTabs>]

G40                                (comp off)
```