Geared Fun

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THIS FUN LITTLE ESSAY describes how the two interlocking toothed gears shown in Figure 1 were modelled and typeset using the TikZ graphics typesetting system[1] together with my pkTikZ LaTeX package.[2]

As a subsystem of the TeX typesetting system, TikZ makes it possible to draw—or should I say "write"—vector-based graphical content directly inside a TeX document. The advantage which TikZ offers a technical writer is that textual, mathematical and graphical content may be brought together under what is essentially a single typesetting regime. The disadvantage is that because TikZ, TeX (and LaTeX) are programmatic in nature, they can be difficult to work with.

In this essay, then, I record some of my own work with TikZ and LaTeX in the hope that it may serve as a reference piece for others who, like me, find TikZ and LaTeX work challenging yet fun. In this essay, I also demonstrate the use of my pkTikZ package. pkTikZ is a simple LATEX package package which encapsulates my local style and command definitions for TikZ. These definitions have helped to maintain aesthetic consistency across many TikZ pictures.

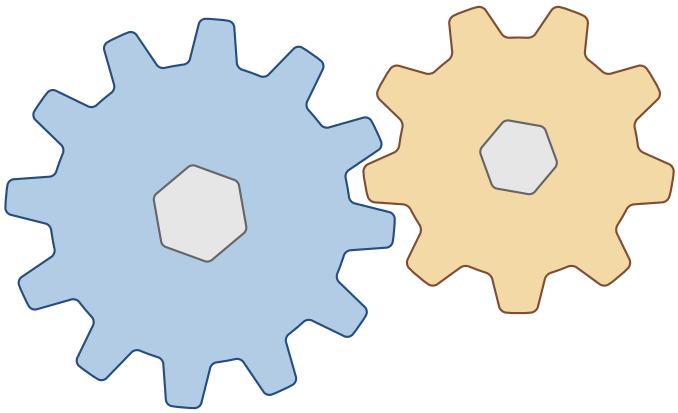

Figure 1: Two interlocking mechanical gears typeset using TikZ and my pkTikZ package. Refer to the source code listings starting on page 4.

One tooth. The essential geometric variables used to parametrise a single tooth of one of the gears are shown in Figure 2 on page 2. The perpendicular axis of rotation of the gear for which the tooth is a part passes through the position $\mathbf{c}$ situated in the global $\{\hat{\mathbf{1}}, \hat{\mathbf{2}}\}$ coordinate system. The gear as whole is oriented by an angle ϕ. If the tooth is the m-th tooth of the gear, then the tooth's angular position is given by the incremental angle θ_m. The incremental angles α, β, δ and the radii ri and ro characterise the geometry of the m-th tooth.

There must obviously be an integral number of teeth on a gear. So:

$$\begin{aligned} (2\alpha + 2\beta + \delta)n &= 2\pi \qquad \text{for some } n = 1, 2, \dots \\ (2\alpha + 2\beta + \delta)(m-1) &= \theta_m \qquad \text{for } m = 1, \dots, n-1 \end{aligned}$$

Therefore

$$\boxed{\theta_m = \frac{2\pi}{n}(m-1)} \qquad \text{for } n = 1, 2, \dots, \; m = 1, \dots, n-1 \tag{1}$$

The geometric character of the toothed gear is characterised not only by the number of teeth, n, but also by the shape of the teeth and the gear's inner radius, ri. Let η be the relative angular width of the top of the

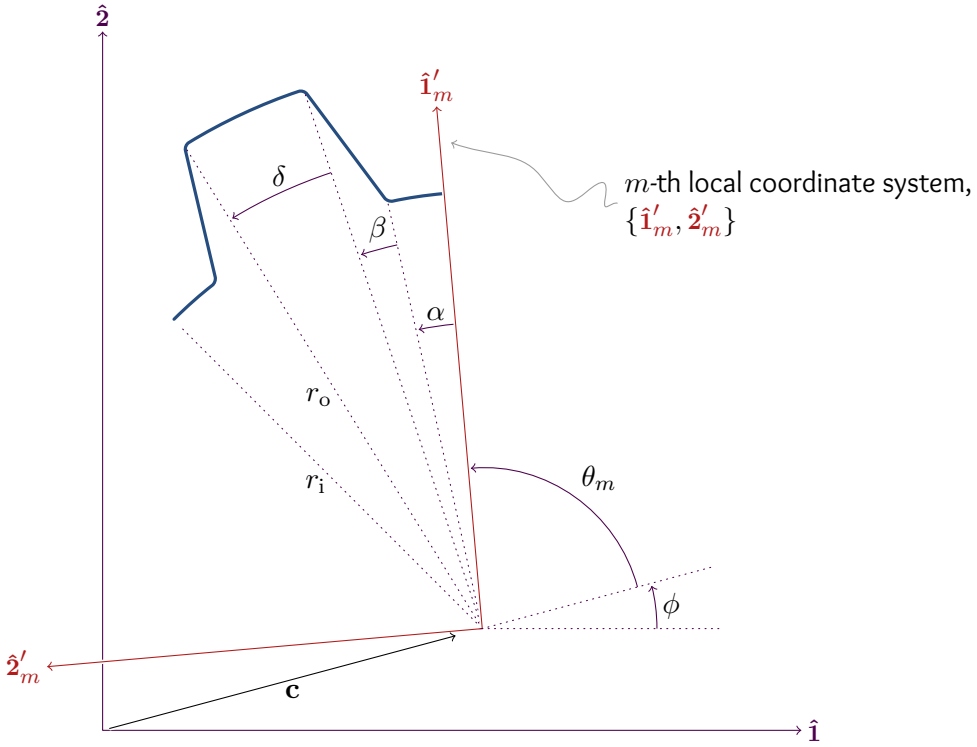

Figure 2: The m-th tooth of a mechanical gear. The perpendicular axis of rotation of the gear passes through the position $\mathbf{c}$ situated in the global $\{\hat{\mathbf{1}}, \hat{\mathbf{2}}\}$ coordinate system. In the source code listing below on page 7, to typeset the tooth, TikZ makes recourse to an m-th local coordinate system, $\{\hat{\mathbf{1}}'_m, \hat{\mathbf{2}}'_m\}$, which has been translated along $\mathbf{c}$ and then rotated by an angle $\phi + \theta_m$. (In the source listing on page 7, search for `shift=` and `rotate=`.) Refer to the source code listings starting on page 7.

tooth, and μ be the same but at the base of the tooth. Then obviously

$$\begin{aligned} \eta &= \frac{\delta}{2\alpha + 2\beta + \delta} \\ \mu &= \frac{2\beta + \delta}{2\alpha + 2\beta + \delta} \end{aligned}$$

Solving for α, β and δ as a function of η, μ and n gives

$$\boxed{\alpha = \frac{\pi}{n}(1 - \mu), \quad \beta = \frac{\pi}{n}(\mu - \eta), \quad \delta = \frac{2\pi\eta}{n}} \tag{2}$$

Two interlocking gears. In the above Figure 1 of the two interlocking toothed gears, one of the gears has been precisely oriented relative to the other gear such that the two gears do in fact interlock. To achieve this orientation, we must calculate the axis position and tilt angle of the second gear as a function of the geometric parameters of the first gear. That is, if the shortest separation between the two gears is specified by a distance t, then referring to Figure 3, we must determine ϕ_b and $\mathbf{c}_\mathrm{b}$ as functions of $\mathbf{c}_\mathrm{a}$, ϕ_a, θ_{am}, $\mathbf{r}_\mathrm{ai}$, $\mathbf{r}_\mathrm{bo}$, m, n and t.

Since $\mathbf{r}_\mathrm{ai}$ is parallel with $\mathbf{r}_\mathrm{bo}$,

$$(2\pi - \theta_{am} - \phi_\mathrm{a}) + (\phi_\mathrm{b} + \alpha_\mathrm{b} + \beta_\mathrm{b} + \frac{\delta_\mathrm{b}}{2}) = \pi$$

which gives

$$\boxed{\phi_\mathrm{b} = \theta_{am} + \phi_\mathrm{a} - \alpha_\mathrm{b} - \beta_\mathrm{b} - \frac{\delta_\mathrm{b}}{2} - \pi} \tag{3}$$

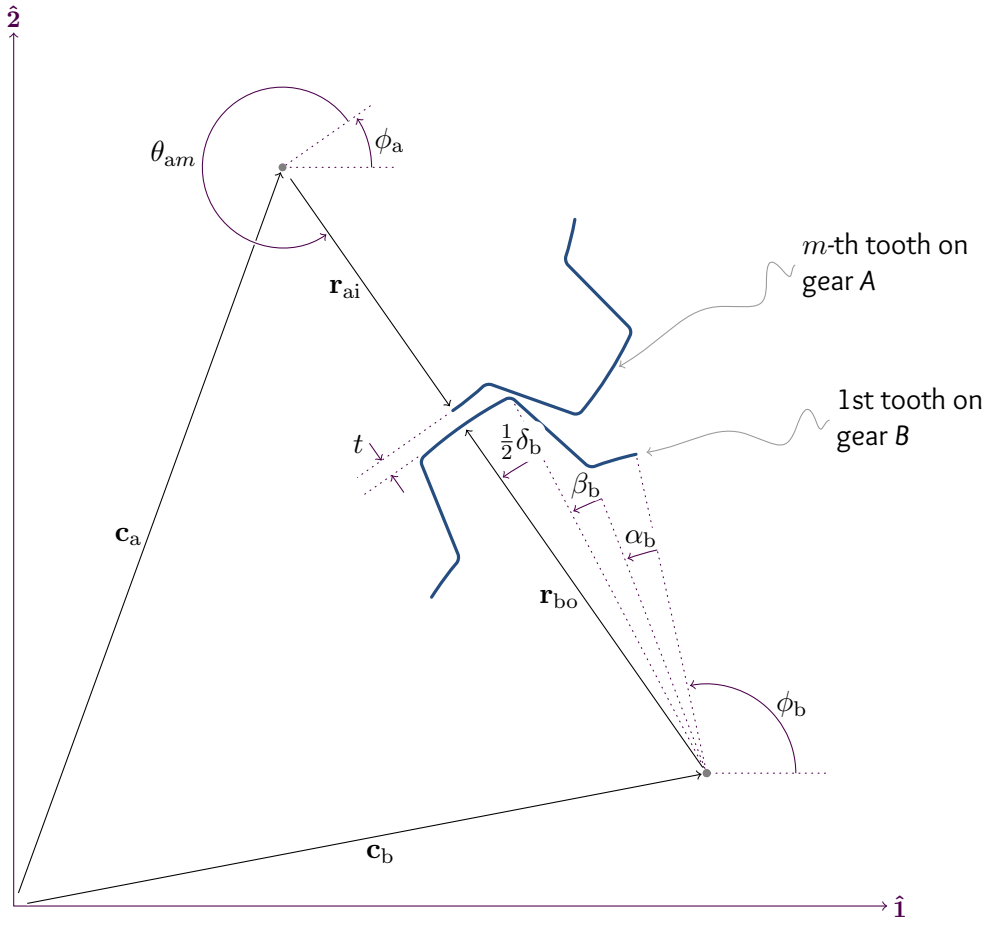

Figure 3: A tooth on gear *A* adjacent to a tooth on gear *B*. Refer to the source code listings starting on page 11.

Inspection of Figure 3 gives the vector expression

$$\begin{aligned} & \mathbf{c}_{\mathrm{a}} + \mathbf{r}_{\mathrm{ai}} + t\hat{\mathbf{r}}_{\mathrm{ai}} = \mathbf{c}_{\mathrm{b}} + \mathbf{r}_{\mathrm{bo}} \\ \Rightarrow \quad & \mathbf{c}_{\mathrm{b}} = \mathbf{c}_{\mathrm{a}} + (r_{\mathrm{ai}} + t)\hat{\mathbf{r}}_{\mathrm{ai}} - \mathbf{r}_{\mathrm{bo}} \end{aligned} \tag{4}$$

Now

$$\hat{\mathbf{r}}_{\mathrm{ai}} = \cos(2\pi - \theta_{am} - \phi_{\mathrm{a}})\hat{\mathbf{1}} + \sin(2\pi - \theta_{am} - \phi_{\mathrm{a}})\hat{\mathbf{2}}$$

and

$$\begin{aligned} \mathbf{r}_{\mathrm{bo}} &= r_{\mathrm{bo}}\big[\cos\big(\phi_{\mathrm{b}} + \alpha_{\mathrm{b}} + \beta_{\mathrm{b}} + \frac{\delta_{\mathrm{b}}}{2}\big)\hat{\mathbf{1}} + \sin\big(\phi_{\mathrm{b}} + \alpha_{\mathrm{b}} + \beta_{\mathrm{b}} + \frac{\delta_{\mathrm{b}}}{2}\big)\hat{\mathbf{2}}\big] \\ &= r_{\mathrm{bo}}\big[\cos(\theta_{am} + \phi_{\mathrm{a}} - \pi)\hat{\mathbf{1}} + \sin(\theta_{am} + \phi_{\mathrm{a}} - \pi)\hat{\mathbf{2}}\big] \qquad \text{using (3)} \\ &= -r_{\mathrm{bo}}\big[\cos(\theta_{am} + \phi_{\mathrm{a}})\hat{\mathbf{1}} + \sin(\theta_{am} + \phi_{\mathrm{a}})\hat{\mathbf{2}}\big] \end{aligned}$$

Substituting into (4) gives

$$\boxed{\begin{aligned} \mathbf{c}_{\mathrm{b}} &= \mathbf{c}_{\mathrm{a}} + (r_{\mathrm{ai}} + t)\hat{\mathbf{r}}_{\mathrm{ai}} - \mathbf{r}_{\mathrm{bo}} \\ &= \big(c_{\mathrm{a}1} + (r_{\mathrm{ai}} + r_{\mathrm{bo}} + t)\cos(\theta_{am} + \phi_{\mathrm{a}})\big)\hat{\mathbf{1}} \\ &\quad + \big(c_{\mathrm{a}2} + (r_{\mathrm{ai}} + r_{\mathrm{bo}} + t)\sin(\theta_{am} + \phi_{\mathrm{a}})\big)\hat{\mathbf{2}} \end{aligned}} \tag{5}$$

Typesetting Figure 1. The diagram in Figure 1 on page 1 was typeset with the following source code files.

The `defs.tex` file:

```
\def\oneVec{\pktikzBasisVector{1}}
\def\onepVec{\pktikzBasisVector{1}'}
\def\twoVec{\pktikzBasisVector{2}}
\def\twopVec{\pktikzBasisVector{2}'}
\def\cVec{\pktikzPositionVector{c}}
\def\cVeca{\cVec_\mathrm{a}}
\def\cVecb{\cVec_\mathrm{b}}
\def\caone{c_\mathrm{a1}}
\def\catwo{c_\mathrm{a2}}
\def\ri{r_\mathrm{i}}
\def\ro{r_\mathrm{o}}
\def\rai{r_\mathrm{ai}}
\def\rbo{r_\mathrm{bo}}
\def\rVec{\pktikzPositionVector{r}}
\def\rUnitVec{\pktikzUnitVector{r}}
\def\rVecai{\rVec_\mathrm{ai}}
\def\rUnitVecai{\rUnitVec_\mathrm{ai}}
\def\rVecbo{\rVec_\mathrm{bo}}
\def\thetaam{\theta_{\mathrm{a}m}}
\def\phia{\phi_\mathrm{a}}
\def\phib{\phi_\mathrm{b}}
\def\alphab{\alpha_\mathrm{b}}
\def\betab{\beta_\mathrm{b}}
\def\deltab{\delta_\mathrm{b}}
```

The `two-gears.tex` file:

```
\makeatletter
\def\drawToothedGear(#1)#2#3#4#5#6#7#8{%
   \begingroup
      \def\gt@@c{#1}%   gear centre position vector
      \def\gt@@phi{#2}% initial tilt angle
      \def\gt@@Ri{#3}%  inner radius
      \def\gt@@n{#4}%   number of gear teeth
      \def\gt@@eta{#5}% angular fraction of gear tooth top
      \def\gt@@mu{#6}%  angular fraction of gear tooth bottom
      \def\gt@@drawColor{#7}%
      \def\gt@@fillColor{#8}%
      %
      % Utility definitions.
      %
      \def\gt@@pi{180}
      %
      \def\gt@@m{1} % Initially, m=1
      \def\gt@@theta{\fpeval{2*\gt@@pi/\gt@@n*(\gt@@m-1)}}
      \def\gt@@alpha{\fpeval{\gt@@pi/\gt@@n*(1-\gt@@mu)}}
      \def\gt@@beta{\fpeval{\gt@@pi/\gt@@n*(\gt@@mu-\gt@@eta)}}
      \def\gt@@delta{\fpeval{2*\gt@@pi/\gt@@n*\gt@@eta}}
      %
      \def\gt@@t{0.3*\gt@@Ri}
      \def\gt@@Ro{\gt@@Ri+\gt@@t} % outer radius
      %
      % Global angular variables.
      %
      \def\gt@@angleA{\fpeval{\gt@@phi+\gt@@theta}}
      %
      \draw[thick,draw=\gt@@drawColor,fill=\gt@@fillColor]
```

```
            (\gt@@c) +(\gt@@phi:\gt@@Ri) %node{$\bullet$}
         foreach \gt@@m in {1,2,...,\gt@@n} {%
            [shift={(\gt@@c)},rotate=\gt@@angleA]
            -- (0:\gt@@Ri)
            [rounded corners=2pt]
            arc[start angle=0,
                end angle=\gt@@alpha,
                radius=\gt@@Ri]
            -- (\gt@@alpha+\gt@@beta:\gt@@Ro)
            arc[start angle=\gt@@alpha+\gt@@beta,
                end angle=\gt@@alpha+\gt@@beta+\gt@@delta,
                radius=\gt@@Ro]
            -- (\gt@@alpha+\gt@@beta+\gt@@delta+\gt@@beta:\gt@@Ri)
            [sharp corners]
            arc[start angle=\gt@@alpha+\gt@@beta+\gt@@delta+\gt@@beta,
                end angle=\gt@@alpha+\gt@@beta+\gt@@delta+\gt@@beta+\gt@@alpha-0.1,
                radius=\gt@@Ri]}
         -- cycle;
      %\draw[draw=pkdocbrown,fill=pkdoclightbrown]
      %   (\gt@@c) circle[radius=\gt@@Ri/3+0.25ex];
      \draw[thick,draw=pkdocdarkgray,fill=pkdoclightgray,rounded corners=1.5pt]
         (\gt@@c)
         [shift={(\gt@@c)},rotate=\gt@@phi]
         (0:\gt@@Ri/3) %node{$\bullet$}
         foreach \ang in {60,120,...,300} {%
            -- (\ang:\gt@@Ri/3)}
         -- cycle;
   \endgroup}
\makeatother
\begin{PkTikzpicture}[scale=1.0]
   %\draw[help lines,<->] (up:7) -- (origin) -- (right:9);
   %
   %\def\setPoint{\pktikzSetLabelledPoint}
   \def\setPoint{\pktikzSetUncircledPoint}
   %
   % Gear 'A'.
   %
   \setPoint{(0,0)}{o1};
   \def\phiA{40}
   \def\RiA{0.12*\linewidth}
   \def\nA{12}
   \def\etaA{8/24}
   \def\muA{15/24}
   \def\thetaA{\fpeval{2*180*(\nA-1)/\nA}}
   \drawToothedGear(o1)%    gear centre position vector
                    {\phiA}% initial tilt angle
                    {\RiA}%  inner radius
                    {\nA}%   number of gear teeth, n
                    {\etaA}% angular fraction of gear tooth top
                    {\muA}%  angular fraction of gear tooth bottom
                    {pkdocblue}%
                    {pkdoclightblue}
   %
   % Gear 'B' oriented relative to gear 'A'.
   %
   \def\RiB{0.8*\RiA}
   \def\nB{9}
   \def\etaB{1/3}
   \def\muB{2/3}
   \def\alphaB{\fpeval{180*(1-\muB)/\nB}}
   \def\betaB{\fpeval{180*(\muB-\etaB)/\nB}}
   \def\deltaB{\fpeval{2*180*\etaB/\nB}}
```

```
    \def\phiB{\fpeval{\thetaA+\phiA-\alphaB-\betaB-\deltaB/2-180}}
    \setPoint{(o1) +(\thetaA+\phiA:\RiA+1.3*\RiB+1.3ex)}{o2};
    \drawToothedGear(o2)%
                    {\phiB}%
                    {\RiB}%
                    {\nB}%
                    {\etaB}%
                    {\muB}%
                    {pkdocbrown}%
                    {pkdoclightbrown}
\end{PkTikzpicture}
```

Typesetting Figure 2. The diagram in Figure 2 on page 2 was typeset with the following source code files.

The `defs.tex` file:

```
\def\oneVec{\pktikzBasisVector{1}}
\def\onepVec{\pktikzBasisVector{1}'}
\def\twoVec{\pktikzBasisVector{2}}
\def\twopVec{\pktikzBasisVector{2}'}
\def\cVec{\pktikzPositionVector{c}}
\def\cVeca{\cVec_\mathrm{a}}
\def\cVecb{\cVec_\mathrm{b}}
\def\caone{c_\mathrm{a1}}
\def\catwo{c_\mathrm{a2}}
\def\ri{r_\mathrm{i}}
\def\ro{r_\mathrm{o}}
\def\rai{r_\mathrm{ai}}
\def\rbo{r_\mathrm{bo}}
\def\rVec{\pktikzPositionVector{r}}
\def\rUnitVec{\pktikzUnitVector{r}}
\def\rVecai{\rVec_\mathrm{ai}}
\def\rUnitVecai{\rUnitVec_\mathrm{ai}}
\def\rVecbo{\rVec_\mathrm{bo}}
\def\thetaam{\theta_{\mathrm{a}m}}
\def\phia{\phi_\mathrm{a}}
\def\phib{\phi_\mathrm{b}}
\def\alphab{\alpha_\mathrm{b}}
\def\betab{\beta_\mathrm{b}}
\def\deltab{\delta_\mathrm{b}}
```

The `draw-gear-tooth.tex` file:

```
\makeatletter
\def\drawGearTooth(#1)#2#3#4#5#6#7{%
   \begingroup
      \def\gt@@c{#1}%   gear centre
      \def\gt@@phi{#2}% initial tilt angle
      \def\gt@@Ri{#3}%  inner radius
      \def\gt@@m{#4}%   the m-th tooth
      \def\gt@@n{#5}%   number of gear teeth
      \def\gt@@eta{#6}% angular fraction of gear tooth top
      \def\gt@@mu{#7}%  angular fraction of gear tooth bottom
      %
      % Utility definitions.
      %
      \def\gt@@pi{180}
      %
      \def\gt@@theta{\fpeval{2*\gt@@pi/\gt@@n*(\gt@@m-1)}}
      \def\gt@@alpha{\fpeval{\gt@@pi/\gt@@n*(1-\gt@@mu)}}
      \def\gt@@beta{\fpeval{\gt@@pi/\gt@@n*(\gt@@mu-\gt@@eta)}}
      \def\gt@@delta{\fpeval{2*\gt@@pi/\gt@@n*\gt@@eta}}
      %
      \def\gt@@t{0.3*\gt@@Ri}
      \def\gt@@Ro{\gt@@Ri+\gt@@t} % outer radius
      %
      % Global angular variables.
      %
      \def\gt@@angleA{\fpeval{\gt@@phi+\gt@@theta}}
      %
      %\draw
      %   (\gt@@c) [shift={(\gt@@c)},rotate=\gt@@angleA,red,very thin,<->]
      %   (up:\gt@@Ri) -- (0,0) -- (right:1.2*\gt@@Ri);
```

```
        \draw[very thick,draw=pkdocblue]
           (\gt@@c) +(\gt@@angleA:\gt@@Ri) %node{$\bullet$};
           [shift={(\gt@@c)},rotate=\gt@@angleA]
           -- (0:\gt@@Ri)
           [rounded corners=2pt]
           arc[start angle=0,
               end angle=\gt@@alpha,
               radius=\gt@@Ri]
           -- (\gt@@alpha+\gt@@beta:\gt@@Ro)
           arc[start angle=\gt@@alpha+\gt@@beta,
               end angle=\gt@@alpha+\gt@@beta+\gt@@delta,
               radius=\gt@@Ro]
           -- (\gt@@alpha+\gt@@beta+\gt@@delta+\gt@@beta:\gt@@Ri)
           [sharp corners]
           arc[start angle=\gt@@alpha+\gt@@beta+\gt@@delta+\gt@@beta,
               end angle=\gt@@alpha+\gt@@beta+\gt@@delta+\gt@@beta+\gt@@alpha-0.1,
               radius=\gt@@Ri];
    \endgroup}
\makeatother
```

The one-tooth.tex file:

```
\begingroup
\newenvironment{MyText}%
   {\begin{tabular}{@{}l@{}}}%
   {\end{tabular}}
\input{draw-gear-tooth.tex}
\makeatletter
\def\drawGearToothWithDims(#1)#2#3#4#5{%
   \begingroup
      \def\gt@c{#1}%   gear centre
      \def\gt@phi{#2}% initial tilt angle
      \def\gt@Ri{#3}%  inner radius
      \def\gt@m{#4}%   the m-th tooth
      \def\gt@n{#5}%   number of gear teeth
      %
      \def\gt@eta{8/24}
      \def\gt@mu{15/24}
      %
      \drawGearTooth(\gt@c){\gt@phi}{\gt@Ri}{\gt@m}{\gt@n}{\gt@eta}
                    {\gt@mu}
      %
      % Utility definitions.
      %
      \def\gt@pi{180}
      %
      \def\gt@theta{\fpeval{2*\gt@pi/\gt@n*(\gt@m-1)}}
      \def\gt@alpha{\fpeval{\gt@pi/\gt@n*(1-\gt@mu)}}
      \def\gt@beta{\fpeval{\gt@pi/\gt@n*(\gt@mu-\gt@eta)}}
      \def\gt@delta{\fpeval{2*\gt@pi/\gt@n*\gt@eta}}
      %
      \def\gt@t{0.3*\gt@Ri}
      \def\gt@Ro{\gt@Ri+\gt@t} % outer radius
      %
      % Global angular variables.
      %
      \def\gt@angleA{\fpeval{\gt@phi+\gt@theta}}
      %
      % Dimensions.
      %
      \draw[pktikzdimension,shift={(\gt@c)},rotate=\gt@angleA]
```

```
            (0,0) -- +(\gt@alpha:\gt@Ri)
            (0,0) -- +(\gt@alpha+\gt@beta:\gt@Ro)
            (0,0) -- +(\gt@alpha+\gt@beta+\gt@delta:\gt@Ro)
                        node[pktikzlabel,midway,below left=-2pt]{$\ro$}
            (0,0) -- +(2*\gt@alpha+2*\gt@beta+\gt@delta:\gt@Ri)
                        node[pktikzlabel,midway,below left=-2pt]{$\ri$};
         \pktikzDrawLabelledAngle[shift={(\gt@c)},rotate={\gt@angleA}]%
                                 {(0,0)}%
                                 {0}%
                                 {\gt@alpha}%
                                 {0.7*\gt@Ri}%
                                 [above]%
                                 {$\alpha$};
         \pktikzDrawLabelledAngle[shift={(\gt@c)},rotate={\gt@angleA}]%
                                 {(0,0)}%
                                 {\gt@alpha}%
                                 {\gt@alpha+\gt@beta}%
                                 {0.9*\gt@Ri}%
                                 [above]%
                                 {$\beta$};
         \pktikzDrawLabelledAngle[shift={(\gt@c)},rotate={\gt@angleA}]%
                                 {(0,0)}%
                                 {\gt@alpha+\gt@beta}%
                                 {\gt@alpha+\gt@beta+\gt@delta}%
                                 {1.1*\gt@Ri}%
                                 [above]%
                                 {$\delta$};
      \endgroup}
   \makeatother
   %
   \begin{PkTikzpicture}[scale=1.0]
      %\draw[help lines,lightgray] (-0.2,-0.2) grid(\linewidth,0.7\linewidth);
      %
      %\def\setPoint{\pktikzSetLabelledPoint}
      \def\setPoint{\pktikzSetUncircledPoint}
      %
      % One tooth of the toothed gear.
      %
      %\def\innerRadius{0.4*\linewidth}
      \def\innerRadius{0.35*\linewidth}
      \def\cLen{0.9*\innerRadius}
      \def\thePhi{15}
      \setPoint{(\thePhi:\cLen)}{c};
      \def\toothNumber{3}
      \def\teeth{9}
      \drawGearToothWithDims(c)%            gear centre position vector
                            {\thePhi}%      initial tilt angle
                            {\innerRadius}% inner radius
                            {\toothNumber}% tooth number, m
                            {\teeth}%       number of gear teeth, n
      %
      \def\oneLen{1.6*\innerRadius}
      \def\twoLen{\oneLen}
      \def\onepLen{1.2*\innerRadius}
      \def\twopLen{\innerRadius}
      %
      \def\thePi{180}
      \def\theTheta{\fpeval{2*\thePi/\teeth*(\toothNumber-1)}}
      %
      \setPoint{(0,0)}{o};
      %
      % Basis vectors 1, 2, 3, 1', 2' and 3'.
```

```
    %
    \draw[pktikzbasisvector,<->]
          (up:\twoLen) node[above]{$\twoVec$}
       -- (o)
       -- (right:\oneLen) node[right]{$\oneVec$};
    \draw[pktikzbasisvectorp,<->,shift={(c)},rotate=\thePhi+\theTheta]
          (up:\twopLen) node[left]{$\twopVec_m$}
       -- (0,0)
       -- (right:\onepLen) node[above](1p){$\onepVec_m$};
    \setPoint{($ (c)!0.9!(1p) $)}{t};
    \pktikzDrawLabelledSquarrow{(t)}%
                               {-20}%
                               {0.15*\oneLen}%
                               {6ex}%
                               {\begin{MyText}
                                  $m$-th local coordinate system,\\
                                  \mbox{%
                                    $\{\textcolor{pktikzbasisvectorpcolor}
                                                {\onepVec_m},
                                       \textcolor{pktikzbasisvectorpcolor}
                                                {\twopVec_m}\}$}
                                \end{MyText}};
    %
    % The gear center position vector.
    %
    \draw[pktikzpositionvector,shorten <=0.5ex,shorten >=2ex]
       (o) -- node[below]{$\cVec$} (c);
    %
    % The orientation angles.
    %
    \draw[pktikzdimension]
          (c) +(right:0.35*\oneLen)
       -- (c)
       -- +(\thePhi:0.35*\oneLen);
    \pktikzDrawLabelledAngle{(c)}%
                            {0}%
                            {\thePhi}%
                            {0.25*\oneLen}%
                            [right]%
                            {$\phi$};
    \pktikzDrawLabelledAngle{(c)}%
                            {\thePhi}%
                            {\thePhi+\theTheta}%
                            {0.23*\oneLen}%
                            [above right]
                            {$\theta_m$};
\end{PkTikzpicture}
\endgroup
```

Typesetting Figure 3. The diagram in Figure 3 on page 3 was typeset with the following source code file.

The `two-tooth.tex` file:

```
\begingroup
\newenvironment{MyText}%
   {\begin{tabular}{@{}l@{}}%
   {\end{tabular}}
\input{draw-gear-tooth.tex}
\begin{PkTikzpicture}
   %\draw[help lines,lightgray] (-0.2,-0.2) grid(\linewidth,0.7\linewidth);
   %
   %\def\setPoint{\pktikzSetLabelledPoint}
   \def\setPoint{\pktikzSetUncircledPoint}
   %
   \setPoint{(0,0)}{o};
   %
   % Basis vectors 1, 2, and 3.
   %
   \def\oneLen{0.7*\linewidth}
   \def\twoLen{\oneLen}
   \draw[pktikzbasisvector,<->]
         (up:\twoLen) node[above]{$\twoVec$}
      -- (o)
      -- (right:\oneLen) node[right]{$\oneVec$};
   %
   % Gear 'A'.
   %
   \def\cLen{0.9*\twoLen}
   \def\phiA{35}
   \def\RiA{0.34*\oneLen}
   \def\mA{7}
   \def\nA{8}
   \def\etaA{8/24}
   \def\muA{15/24}
   \def\thetaA{\fpeval{2*180*(\mA-1)/\nA}}
   \setPoint{(70:\cLen)}{ca};
   \drawGearTooth(ca){\phiA}{\RiA}{\mA}{\nA}{\etaA}{\muA}
   %
   % Some dimensions for gear 'A'.
   %
   \draw[pktikzpositionvector,shorten <=1ex]
         (o)
      -- node[left]{$\cVeca$} (ca);
   \def\angleA{\fpeval{\phiA+\thetaA}}
   \setPoint{(ca) +(\angleA:\RiA)}{p};
   \draw[pktikzpositionvector,shorten <=1ex]
         (ca)
      -- node[left]{$\rVecai$} (p);
   \draw[pktikzdimension]
         (ca)
         +(right:0.4*\RiA)
      -- (ca)
      -- +(\phiA:0.4*\RiA);
   \pktikzDrawCircledPoint{(ca)};
   \pktikzDrawLabelledAngle{(ca)}%
                           {0}%
                           {\phiA}%
                           {0.3*\RiA}%
                           [right]%
                           {$\phia$};
   \pktikzDrawLabelledAngle[pktikzshadowed]%
```

```
                            {(ca)}%
                            {\phiA}%
                            {\angleA}%
                            {0.27*\RiA}%
                            [left]%
                            {$\thetaam$};
    \pktikzDrawLabelledSquarrow{(ca) +(\angleA+23:1.3*\RiA)}%
                               {30}%
                               {0.15*\oneLen}%
                               {6ex}%
                               {\begin{MyText}
                                   $m$-th tooth on\\
                                   gear \emph{A}
                                \end{MyText}};
    %
    % Gear 'B' oriented relative to gear 'A'.
    %
    \def\RiB{1.1*\RiA}
    \def\mB{1}
    \def\nB{8}
    \def\etaB{8/24}
    \def\muB{15/24}
    \def\toothSep{1.3ex}
    \def\alphaB{\fpeval{180*(1-\muB)/\nB}}
    \def\betaB{\fpeval{180*(\muB-\etaB)/\nB}}
    \def\deltaB{\fpeval{2*180*\etaB/\nB}}
    \def\phiB{\fpeval{\phiA+\thetaA-\alphaB-\betaB-\deltaB/2-180}}
    \pktikzSetCircledPoint{(ca) +(\angleA:\RiA+1.3*\RiB+\toothSep)}{cb};
    \drawGearTooth(cb){\phiB}{\RiB}{\mB}{\nB}{\etaB}{\muB}
    %
    % Some dimensions for gear 'B'.
    %
    \draw[pktikzpositionvector,shorten <=1ex]
          (o)
       -- node[below right]{$\cVecb$} (cb);
    \def\angleB{\fpeval{\phiB+\alphaB+\betaB+\deltaB/2}}
    \setPoint{(cb) +(\angleB:1.3*\RiB)}{q};
    \draw[pktikzpositionvector,shorten <=0.5ex]
          (cb)
       -- node[left]{$\rVecbo$} (q);
    \draw[pktikzdimension]
          (cb)
          +(right:0.4*\RiA)
       -- (cb)
       -- +(\phiB:\RiB)
          (cb)
          +(\phiB+\alphaB:\RiB)
       -- (cb)
       -- +(\phiB+\alphaB+\betaB:1.3*\RiB);
    \pktikzDrawCircledPoint{(cb)};
    \pktikzDrawLabelledAngle{(cb)}%
                            {0}%
                            {\phiB}%
                            {0.3*\RiA}%
                            [right=0.5ex]%
                            {$\phib$};
    \pktikzDrawLabelledAngle{(cb)}%
                            {\phiB}%
                            {\phiB+\alphaB}%
                            {0.7*\RiB}%
                            [above]%
                            {$\alphab$};
```

```
    \pktikzDrawLabelledAngle{(cb)}%
                             {\phiB+\alphaB}%
                             {\phiB+\alphaB+\betaB}%
                             {0.9*\RiB}%
                             [above]%
                             {$\betab$};
    \pktikzDrawLabelledAngle{(cb)}%
                             {\phiB+\alphaB+\betaB}%
                             {\angleB}%
                             {1.1*\RiB}%
                             [above]%
                             {$\frac{1}{2}\deltab$};
    \pktikzDrawLabelledSquarrow{(cb) +(\phiB:\RiB)}%
                               {10}%
                               {0.13*\oneLen}%
                               {6ex}%
                               {\begin{MyText}
                                   1st tooth on\\
                                   gear \emph{B}
                                \end{MyText}};
    %
    % Separation 't'.
    %
    \draw[pktikzdimension]
          (q)
          +(\angleB+90:4ex)
       -- +(\angleB+90:9ex) coordinate(q2)
          (p)
       -- +(\angleB+90:9ex) coordinate(p2);
    \draw[draw=pktikzdimensioncolor,<-]
       ($ (p)!0.7!(p2) $) -- +(\angleB:1.5ex) node[left]{$t$};
    \draw[draw=pktikzdimensioncolor,<-]
       ($ (q)!0.7!(q2) $) -- +(\angleB+180:1.5ex);
\end{PkTikzpicture}
\endgroup
```

References

[1] Till Tantau. PGF and TikZ—Graphic systems for TEX. https://sourceforge.net/projects/pgf/.

[2] Paul Kotschy. pkTikZ: A simple LATEX package providing Paul Kotschy's local style and command definitions for use with TikZ. *Still to be published*.