Companion software for "Volker Ziemann, *Hands-on Accelerator physics using MATLAB, CRCPress, 2019*" (https://www.crcpress.com/9781138589940)

Vacuum calculations (Section 13.5.3)

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Here we describe a minimal version of the vacuum calculation code `vaktrak`, discussed in

- Volker Ziemann, *Vacuum tracking,* SLAC-PUB-5962, 1992.

It determines the longitudinal profile of the pressure and gasflow along a linear vacuum system in the regime of conduction limited flow. Such a vacuum system of n elements is defined by a $n \times 6$ array, where the first column contains a code, describing the type of element, the second element contains a repeat-code for that element, and the next four entries are related to the length, conductance c or C, pump speed s or S, and outgassing rate q of the respective element. Here is a short summary, but check out the details in Section 13.5.3.

supported codes with ordering: CODE,repeat,L,c,s,q

Conductance only: 1, rep, L, c, 0, 0

Short pump: 2, 1, 0, 0, S, 0

Short gas source: 3, 1, 0, 0, 0, dQ

Generic element: 4, rep, L, c, s, q

Larger systems can be assembled from short sections with repmat() and flip().

We start the simulation by defining functions that return the 3×3 matrices for the conductance, a short pump, and a short gas source.

```
clear all; close all
conduc=@(C)[1,-1/C,0; 0,1,0; 0,0,1];  % matrix for conductance
pump=@(S)[1,0,0;-S,1,0;0,0,1];         % matrix for short pump
outgas=@(dQ)[1,0,0;0,1,dQ;0,0,1];      % matrix for gas source, leak
```

Now we define a section `vacsys` of our vacuum system, defined by a localized outgassing source (code=3), a pipe, made of 100 segments, 10 cm long each, and a short pump with a pump pseed of 100 l/s.

```
vaksys=[ 3,     1,     0,     0,     0,     1e-6;    % outgas, dQ
         1,   100,   0.1,    10,     0,     0;       % conductance, c
         2,     1,     0,     0,   100,     0]      % pump, S
```

```
vaksys = 3×6
    3.0000    1.0000         0         0         0    0.0000
    1.0000  100.0000    0.1000   10.0000         0         0
    2.0000    1.0000         0         0  100.0000         0
```

The vacuum system v consists of two sections vaksys of which the second one is traversed in the reverse order. Finally we repeat this system 2 times and call the entire system `beamline`, just as we did for the beam optical systems in Chapter 3.

```
v=[vaksys; flip(vaksys,1)];
beamline=repmat(v,2,1)       % description of the complete system
```

```
beamline = 12×6
    3.0000    1.0000         0         0         0    0.0000
    1.0000  100.0000    0.1000   10.0000         0         0
    2.0000    1.0000         0         0  100.0000         0
    2.0000    1.0000         0         0  100.0000         0
    1.0000  100.0000    0.1000   10.0000         0         0
    3.0000    1.0000         0         0         0    0.0000
    3.0000    1.0000         0         0         0    0.0000
    1.0000  100.0000    0.1000   10.0000         0         0
    2.0000    1.0000         0         0  100.0000         0
    2.0000    1.0000         0         0  100.0000         0
     ⋮
```

The following lines are needed for accounting purposes: `nlines` are the number of lines in the `beamline`, `nmat` is the number of matrices and `Racc` will be filled with all the transfer matrices from the start of the system to the end of each segment, while `spos` keeps track of the longitudinal position of segments.

```
nlines=size(beamline,1);       % number of elements in beamline
nmat=sum(beamline(:,2))+1;     % number of matrices, incl repeat count
Racc=zeros(3,3,nmat);          % accumulated transfer matrices
Racc(:,:,1)=eye(3);            % initialize the first one
spos=zeros(nmat,1);            % array for element (end-)positions
```

In the next snippet we loop over all lines in the beamline and then over all segments and then assign `Rcurr` to the 3×3 matrix for the appropriate element (as specified by the code in the first column of `beamline`). After these loops, we left-multiply `Rcurr` to the transfer matrix up to the previous element `Racc(:,:,ic-1)` and update `spos`. Finally we give the transfer matrix that takes us to the end the name `R0`.

```
ic=1;
for line=1:nlines              % loop over elements
  for seg=1:beamline(line,2)   % and over the segements of each element
    ic=ic+1;                   % element counter
    Rcurr=eye(3);              % initialize to unit matrix
    switch beamline(line,1)    % brach accoding to element
      case 1       % pure conductance
        C=beamline(line,4)/beamline(line,3);    % C=c/L
        Rcurr=conduc(C);                        % large C
      case 2       % short pump, zero length
        Rcurr=pump(beamline(line,5));           % large S
      case 3  % point-like gas source, zero length
        Rcurr=outgas(beamline(line,6));         % large dQ
      case 4  % generic element, c,s,q,L are all given
        Rcurr=csql(beamline(line,4),beamline(line,5),...
          beamline(line,6),beamline(line,3));
      otherwise
         disp('unsupported code')
    end
    Racc(:,:,ic)=Rcurr*Racc(:,:,ic-1);      % add new element
    spos(ic)=spos(ic-1)+beamline(line,3);   % update the position
  end
```

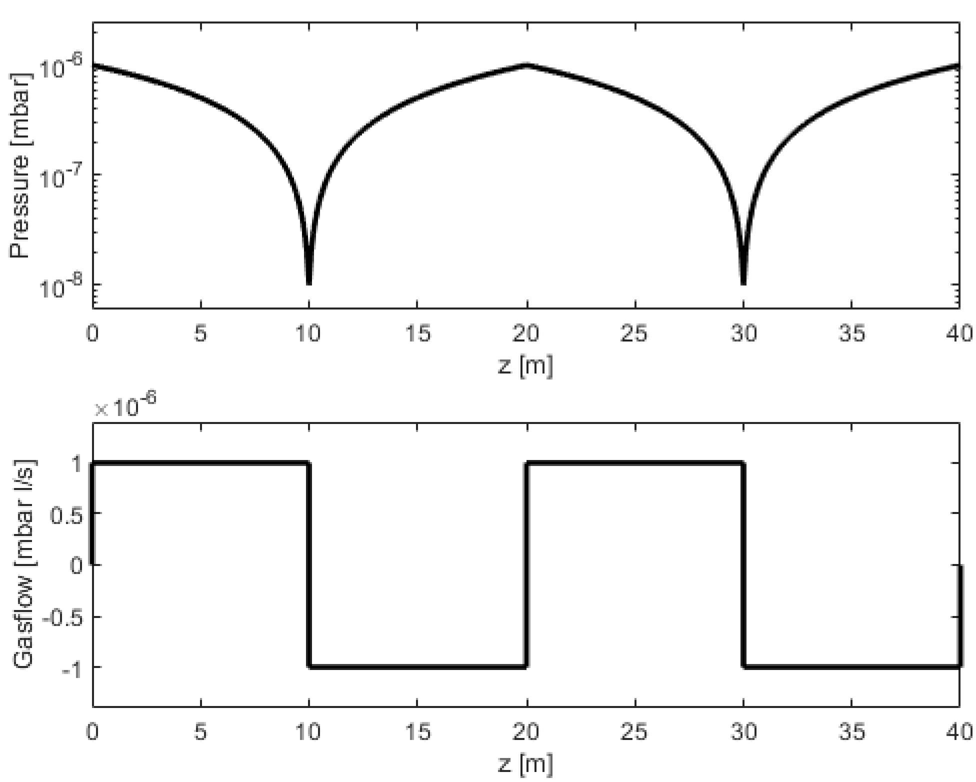
```
end
R0=Racc(:,:,end);    % alias for the start-to-end matrix
```

If we assume that the entire system is flanged off at the ends (gasflow: `Ql=Qr=0`), we can find the equilibrium pressure on the left end `Pl` and at the right end `Pr` from `R0`. From this we construct the 3×1 vector with the initial condition `P0r` and propagate it through the vacuum system in the loop over `k`.

```
Pr=-R0(2,3)/R0(2,1);
Pl=R0(1,3)-R0(1,1)*R0(2,3)/R0(2,1);
P0r=[Pr;0;1]; % vector at start
pressure=zeros(nmat,1); gasflow=pressure;   % allocate memory
for k=1:nmat               % loop over all elements
  PP=Racc(:,:,k)*P0r;      % and calculate [P;Q;1] at end of each element
  pressure(k)=PP(1);       % stuff into arrays used for plotting
  gasflow(k)=PP(2);
end
```

At this point we are ready to display the pressure profile along our vacuum system in the top plot and the corresponding gas flow in the bottom plot.

```
subplot(2,1,1); semilogy(spos,pressure,'k','LineWidth',2);
xlim([0,spos(end)]); ylim([0.6*min(pressure),2.5*max(pressure)])
xlabel('z [m]'); ylabel('Pressure [mbar]');
subplot(2,1,2); plot(spos,gasflow,'k','LineWidth',2);
xlim([0,spos(end)]); ylim([1.4*min(gasflow),1.4*max(gasflow)])
xlabel('z [m]'); ylabel('Gasflow [mbar l/s]')
```



Now define your own vacuum system and simulate it.

Appendix

here we define a function csql() that receives the per-meter conductance c, the per-meter pump speed s, the per-meter outgassing q, and the length L of an element and returns the transfer matrix from Equation 13.3.

```
function R=csql(c,s,q,L)
R=eye(3);
sq=sqrt(s/c); cc=cosh(sq*L); ss=sinh(sq*L);
R(1,1)=cc;
R(1,2)=-ss/(c*sq);
R(1,3)=-q*(cc-1)/s;
R(2,1)=-c*sq*ss;
R(2,2)=cc;
R(2,3)=q*ss/sq;
end
```