

Cylinder volume function for SVC engines

Ylva Nilsson

Department of Electrical Engineering
Vehicular systems, Linköping University

Abstract

One of the features of the SAAB Variable Compression engine (SVC) is its possibility to change the compression by tilting the top of the engine. Due to the change in geometry, the standard equation used to calculate the cylinder volume as function of crank angle may not give sufficiently accurate result.

A new cylinder volume function, that is specially designed for the SVC, is derived and described. It is written on the form $V(\theta, v) = V_c(v) + V_d(\theta, v)$, where θ is the crank angle, v the tilt angle, V_c the clearance volume, and V_d the volume displaced by the piston. It is shown that the biggest relative deviation between the standard volume function and the SVC volume function is approximately 6%. It is also shown that by adjusting the crank angle input to the standard volume function so that the TDC coincide with the actual TDC, that is $V(\theta, v) = V_c(v) + V_{std}(\theta - \theta_{TDC})$, the relative error caused by using the standard volume function is reduced by a factor 10.

Contents

1	Introduction	5
2	Geometry	5
3	Position of the piston	5
3.1	Change of base	9
3.2	Top and bottom dead center	10
4	Cylinder volume	11
5	Motion of the piston	12
6	Program package	13
7	Comparative study	14
7.1	A comparison between the standard volume function and the SVC volume function	15
7.2	The effect of pin-off	18
8	Conclusions	19
A	Matlab code	21
A.1	SVCdata.m	21
A.2	SVCvolume.m	22
A.3	tilt.m	25
A.4	stdvolume.m	26

Nomenclature

θ	Crank angle
v	Tilt angle
r_c	Compression ratio
V_c	Clearance volume
V_d	Displaced volume
B	Cylinder bore
l	Piston pin
a	Crank rod
r	Tilt radius
x	Vertical distance between crank and tilt axis
y	Horizontal distance between crank and tilt axis
SVC	SAAB Variable Compression
TDC	Top dead center
BDC	Bottom dead center

1 Introduction

SAAB Automobile AB has developed a new type of engine, called the SAAB Variable Compression engine (SVC), with which it is possible to vary the compression ratio. The advantage is a gain in efficiency, since an increase in compression ratio also increases the efficiency. The compression ratio is limited by knock, which can severely damage the engine. A compromise between demands on efficiency and knock intensity has to be made. When designing an engine with fixed compression ratio, the compression ratio is set to a low value at low loads to avoid heavy knock at high loads. With an SVC engine it is possible to optimize the efficiency at every operating point.

The standard function used to calculate the cylinder volume as function of crank angle is:

$$V(\theta, r_c) = V_c(r_c) + \frac{\pi B^2}{4}(l + a - s(\theta))$$

where s is the distance between the crankshaft and the piston pin, i.e.

$$s(\theta) = a \cos \theta + \sqrt{l^2 - a^2 \sin^2 \theta}$$

Due to the change in engine design, this function may not give sufficiently accurate results. A new function that is suited for the SVC engine has to be derived.

2 Geometry

A simple sketch of the SVC engine is shown in figure 1. What makes the SVC engine unique is that the top of the engine can be tilted and thereby change the compression ratio. The top of the engine moves around an axis placed at some distance from the crank axis (figure 2). When the top is tilted, the cylinder is further away from the crank axis, and the consequence is that the piston does not reach as high up in the cylinder as it does when the top is not tilted. Thereby the clearance volume increases. Since the piston stroke is almost unaffected by the tilt, the compression ratio is decreased.

3 Position of the piston

The displaced cylinder volume depends on the motion of the piston inside the cylinder. When the piston moves downwards, the volume increases and when it moves upwards it decreases. The situation is depicted in figure 3. In the figure, the position of the piston is represented by P_2 . P_1 is the point where the crank rod is connected to the piston pin. P_3 is the point where a line that goes through the tilt axis and is perpendicular to the direction of

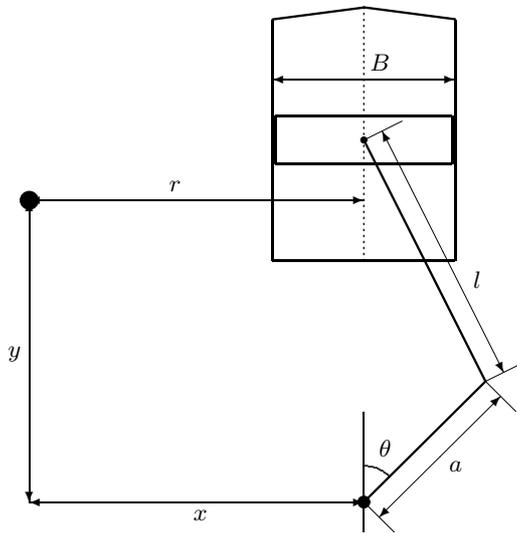


Figure 1: The SVC engine

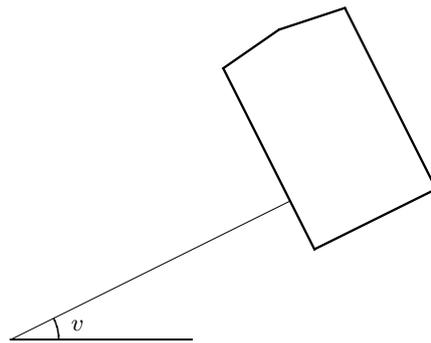


Figure 2: The cylinder is tilted to decrease the compression ratio.

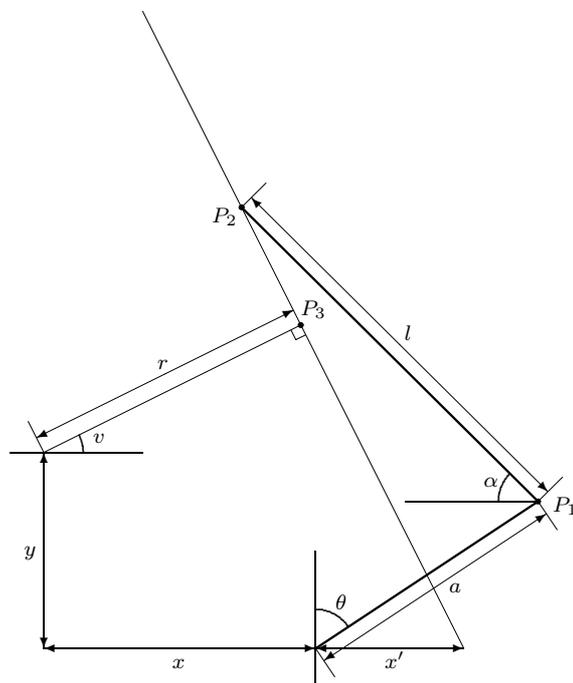


Figure 3: Definition of points and angles used in the derivation of the cylinder volume function

motion of the piston, crosses a line that is parallel to the direction of motion of the piston and is centered in the cylinder.

The chosen coordinate system has its origin at the crank axis, the first and second base vector points in the same direction as the crank rod at a crank angle of $\pi/2$ and 0 respectively. In this coordinate system the position of point P_2 is

$$P_2 = P_1 + \begin{pmatrix} -l \cos \alpha \\ l \sin \alpha \end{pmatrix} \quad (1)$$

and P_1 is

$$P_1 = \begin{pmatrix} a \sin \theta \\ a \cos \theta \end{pmatrix} \quad (2)$$

The angle α is not known and is to be determined. Another way to write P_2 is

$$P_2 = \begin{pmatrix} x' \\ 0 \end{pmatrix} + \begin{pmatrix} -s_1 \sin v \\ s_1 \cos v \end{pmatrix} \quad (3)$$

where s_1 is the distance from the point $(x' \ 0)^T$ to P_2 . Equation 1 and 3 gives enough information to solve for α and s_1 . Since

$$\begin{pmatrix} a \sin \theta - l \cos \alpha \\ a \cos \theta + l \sin \alpha \end{pmatrix} = \begin{pmatrix} x' - s_1 \sin v \\ s_1 \cos v \end{pmatrix}$$

s_1 is given directly by the second component

$$s_1 = \frac{1}{\cos v} (a \cos \theta + l \sin \alpha)$$

which inserted into the first component gives the following expression

$$\cos \alpha - \tan v \sin \alpha = \frac{a}{l} (a \sin \theta - x' + a \tan v \cos \theta)$$

The left hand side of the last equation can be rewritten to

$$\cos \alpha - \tan v \sin \alpha = \frac{\cos(v + \alpha)}{\cos v}$$

which gives

$$\cos(\alpha + v) = \frac{a}{l} (\cos v \sin \theta + \sin v \cos \theta) - \frac{x'}{l} \cos v = \frac{a}{l} \sin(\theta + v) - \frac{x'}{l} \cos v$$

The angle α can be solved from the equation above:

$$\alpha = \arccos \left(\frac{a}{l} \sin(v + \theta) - \frac{x'}{l} \cos v \right) - v \quad (4)$$

The point x' can be determined from the position of P_3 . P_3 can be described in two ways:

$$P_3 = \begin{pmatrix} -x + r \cos v \\ y + r \sin v \end{pmatrix}$$

$$P_3 = \begin{pmatrix} x' - s_2 \sin v \\ s_2 \cos v \end{pmatrix}$$

where s_2 is the distance from the point $(x' \ 0)^T$ to P_3 . By combining these two equations, s_2 can be eliminated and x' determined:

$$x' = \tan v (y + r \sin v) - x + r \cos v \quad (5)$$

The calculations described in this section can be summarized in the following model for the position of the piston:

$$\begin{aligned} P_2(\theta, v) &= \begin{pmatrix} x' \\ 0 \end{pmatrix} + \frac{a \cos \theta + l \sin \alpha}{\cos v} \begin{pmatrix} -\sin v \\ \cos v \end{pmatrix} \\ \alpha &= \arccos \left(\frac{a}{l} \sin(v + \theta) - \frac{x'}{l} \cos v \right) - v \\ x' &= -x + r \cos v + \tan v (y + r \sin v) \end{aligned}$$

3.1 Change of base

The part we are interested in is the position of the piston. The movement of the piston follows a straight line, and therefore we should be able to reduce the number of coordinates from two to one. This can be done by introducing a new coordinate system, whose first base vector is perpendicular to the direction of movement and second is parallel. If the base of the original coordinate system is called \mathbf{e} and the new one is called \mathbf{f} , then

$$\mathbf{f} = \begin{pmatrix} \cos v & \sin v \\ -\sin v & \cos v \end{pmatrix} \mathbf{e} = \mathbb{T} \mathbf{e}$$

The position of the piston is

$$P_2 = A_e \mathbf{e} = A_e \mathbb{T}^{-1} \mathbf{f}$$

In the new base P_2 will therefore be described as:

$$\begin{aligned} P_{2f}(\theta, v) &= (x'(v) - s_1 \sin v \quad s_1(\theta, v) \cos v) \begin{pmatrix} \cos v & -\sin v \\ \sin v & \cos v \end{pmatrix} \mathbf{f} = \\ &= x'(v) \begin{pmatrix} \cos v \\ -\sin v \end{pmatrix} + s_1(\theta, v) \begin{pmatrix} 0 \\ 1 \end{pmatrix} \end{aligned}$$

Now the change in piston position as function of crank angle is described by only one coordinate, i.e. the second row, but we still have some information left in the first row. Since we would like to be able to compare the position of piston relative to the cylinder even though the tilt angle has changed, we would like to get rid of x' since it varies with the tilt. By placing the origin of the new coordinate system in a point that is fixed to

the cylinders, we can accomplish this. A suitable point would be P_3 as we already now its position.

$$P_3(\theta, v) = \begin{pmatrix} x' \\ 0 \end{pmatrix} + s_2(v) \begin{pmatrix} -\sin v \\ \cos v \end{pmatrix}$$

where s_2 is

$$s_2(v) = \frac{y + r \sin v}{\cos v}$$

In the new base P_3 is

$$P_{3f} = x' \begin{pmatrix} \cos v \\ -\sin v \end{pmatrix} + s_2 \begin{pmatrix} 0 \\ 1 \end{pmatrix}$$

and the difference between P_{2f} and P_{3f} is

$$P_{2f} - P_{3f} = (s_1 - s_2) \begin{pmatrix} 0 \\ 1 \end{pmatrix}$$

The first row no longer contains any information since it is zero. The distance between the piston and P_3 is thus $s_1 - s_2$.

To summarize the change of coordinate system, the new system is tilted an angle v compared to the old one and has its origin in the point P_3 . The position of the piston in the new coordinate system is:

$$P^\circ(\theta, v) = s_1 - s_2 = \frac{1}{\cos v} (a \cos \theta + l \sin \alpha - y - r \sin v)$$

3.2 Top and bottom dead center

The position of top and bottom dead center changes with tilt angle, and does not in general coincide with a crank angle of 0 and 180° respectively. The crank rod and piston pin have the same direction at TDC and BDC. The situation at TDC is shown in figure 4, where the angle β is equal to $-\theta_{TDC}$.

From figure 4 we get,

$$\frac{x'}{\sin \gamma} = \frac{a + l}{\sin \left(\frac{\pi}{2} - v \right)}$$

which gives that the angle γ

$$\gamma = \arcsin \left(\frac{x'}{a + l} \sin \left(\frac{\pi}{2} - v \right) \right)$$

It can also be seen in the figure that

$$\beta + \frac{\pi}{2} = \pi - \gamma - \left(\frac{\pi}{2} - v \right)$$

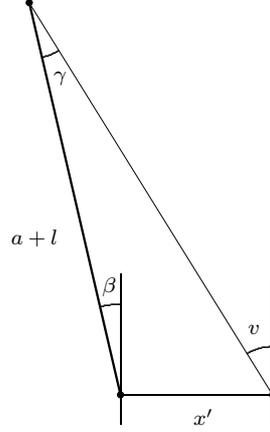


Figure 4: Piston at TDC

and thus

$$\theta_{TDC} = \arcsin\left(\frac{x'}{a+l} \cos v\right) - v$$

The position of BDC can be determined with the same method as TDC.

$$\theta_{BDC} = \pi - v + \arcsin\left(\frac{x'}{l-a} \cos v\right)$$

4 Cylinder volume

The cylinder volume consists of a compression volume and the volume displaced by the movement of the piston, that is

$$V(\theta, v) = V_c(v) + \frac{\pi B^2}{4} (P^\circ(\theta_{TDC}(v), v) - P^\circ(\theta, v)) \quad (6)$$

where V_c is the compression volume. The size of the compression volume depends on the tip angle. When the tip angle increases, the compression volume also increases.

$$V_c(v) = V_c(0) + \frac{\pi B^2}{2} (P^\circ(\theta_{TDC}(0), 0) - P^\circ(\theta_{TDC}(v), v)) \quad (7)$$

When the engine is at its upright position, that is $v = 0$, the compression ratio should have a specified value. This will be used as a reference for the calculation of r_c for other tilt angles. Using the definition of compression ratio

$$r_c = \frac{V_{max}}{V_{min}}$$

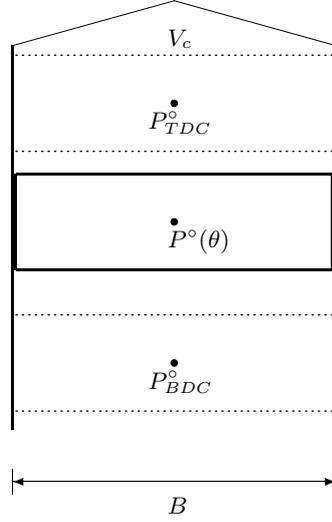


Figure 5: An engine cylinder with piston

the compression volume at upright position can be calculated from:

$$V_c(0) = \frac{\pi B^2}{4((r_c)_{v=0} - 1)} (P^\circ(\theta_{TDC}(0), 0) - P^\circ(\theta_{BDC}(0), 0)) \quad (8)$$

The definition is also useful when determining the compression ratio at different tip angles:

$$r_c(v) = 1 + \frac{\pi B^2}{4V_c} (P^\circ(\theta_{TDC}(v), v) - P^\circ(\theta_{BDC}(v), v)) \quad (9)$$

5 Motion of the piston

In many calculations, not only the volume but also its differential with respect to crank angle is of great importance. The change in cylinder volume depends on the movement of the piston according to:

$$\frac{dV}{d\theta} = \frac{\pi B^2}{4} \frac{d}{d\theta} P^\circ(\theta, v)$$

where

$$\frac{dP^\circ}{d\theta} = \frac{1}{\cos v} \left(a \sin \theta - l \cos \alpha \cdot \frac{d\alpha}{d\theta} \right)$$

In section 3 the angle α was calculated to

$$\alpha = \arccos \left(\frac{a}{l} \sin(v + \theta) - \frac{x'}{l} \cos v \right) - v \quad (10)$$

To simplify the reading and writing, a new variable named f is introduced. It is defined as:

$$f = \frac{1}{l} (a \sin(\theta + v) - x' \cos v)$$

The derivative of α can now be written:

$$\frac{d\alpha}{d\theta} = \frac{-1}{\sqrt{1-f^2}} \cdot \frac{df}{d\theta}$$

where

$$\frac{df}{d\theta} = \frac{a \cos(\theta + v)}{l}$$

6 Program package

The software for calculating the cylinder volume consists of four files; `tilt.m`, `SVCvolume.m`, `SVCdata.m`, and `stdvolume.m`. These are presented in Appendix A

The function `SVCdata` initiates the global variable `ENGINE` which is used in all the other functions. `ENGINE` is a structure containing the geometry of the SVC engine. All data is in SI-units.

`SVCvolume` calculates the volume and its differential as function of crank and tilt angles for an SVC engine. It also calculates the compression ratio and clearance volume or crank angle at TDC and BDC, as function of tilt angle. Type `help SVCvolume` in Matlab to get some more information.

If the desired output from `SVCvolume` is volume or its differential, the crank angle and tilt angle should be passed as input. Usually, the compression ratio is known but not the tilt angle and there is no obvious way to calculate the tilt from the compression. The function `tilt` uses linear interpolation to find the tilt angle for a given compression ratio.

`stdvolume` calculates the cylinder volume according to the standard volume function. It uses the global variable `ENGINE` as well. The standard model for calculating cylinder volume is

$$V(\theta, r_c) = V_c(r_c) + \frac{\pi B^2}{4} (l + a - s(\theta))$$

where s is the distance between the crankshaft and the piston pin, that is

$$s(\theta) = a \cos \theta + \sqrt{l^2 - a^2 \sin^2 \theta}$$

The compression ratio can either be passed as input or be included in `ENGINE`.

7 Comparative study

The Matlab functions described in the previous section were used to study the behavior of an SVC engine. First the compression ratios were calculated as function of tilt angles. The result, shown in figure 6, is according to the information given by SAAB. At a tilt of 4° the compression should be 8 and at 0° it should be 14. It is obvious that the latter requirement was to be fulfilled since this point was used as a reference.

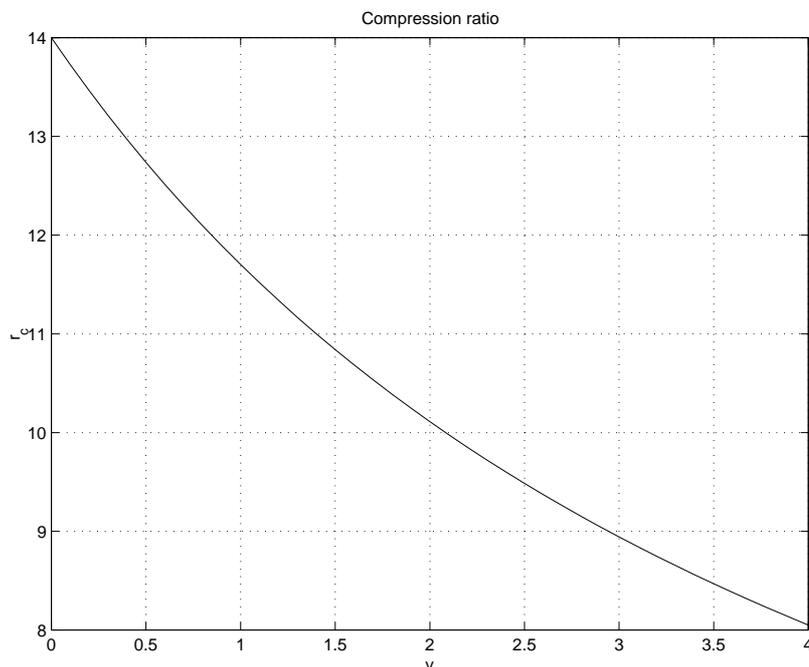


Figure 6: Compression ratio as function of tilt angle

The variation in crank angle at top dead center and bottom dead center is shown in figure 7. As can be seen, the variation is almost linear. The TDC and BDC position can thus be determined from:

$$\begin{aligned}\hat{\theta}_{TDC} &= c_1 + c_2 \cdot v \\ \hat{\theta}_{BDC} &= d_1 + d_2 \cdot v\end{aligned}$$

Using the method of least squares, c_1 , c_2 , d_1 , and d_2 are identified as $-11.1 \cdot 10^{-3}$ [rad], -0.512 , 3.12 [rad] and -0.136 respectively.

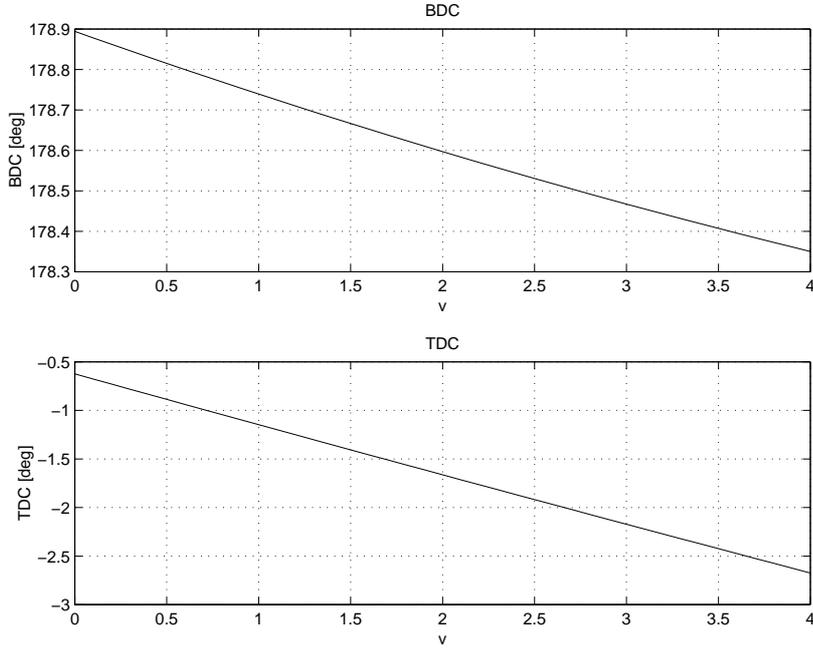


Figure 7: Bottom and top dead center as function of tilt angle

7.1 A comparison between the standard volume function and the SVC volume function

In an SVC engine, the cylinder is not centered above the crankshaft and the cylinder is often tilted, therefore the standard volume function will not give accurate result. For example, the position of top dead center (TDC) and bottom dead center (BDC) is different, as shown in Figure 7. Due to the asymmetrical placement of the cylinder, θ_{TDC} is not zero even when $v = 0$, and in addition the shape of the volume curve will change. In Figure 8, the cylinder volume at $v = 4^\circ$ has been calculated in two ways, using the SVC volume function and using the standard volume function. The choice of tilt angle is due to that $v = 4^\circ$ is the highest possible tilt, and therefore will have the greatest deviation from the standard volume function. The relative error at this tilt angle is as big as 6%.

The greatest deviation in volume differential between the two models at $v = 4^\circ$ is at crank angles close to TDC (Figure 9). Note that the bottom picture shows the error, not the relative error.

The most significant difference between the outcome of the standard and the SVC volume function is that TDC is not positioned at $\theta = 0$ in the latter case. By adjusting the crank angle with the deviation in TDC, the standard volume function gives better results. As can be seen in Figure 7, it is a almost linear relationship between TDC position and tilt angle. The crank

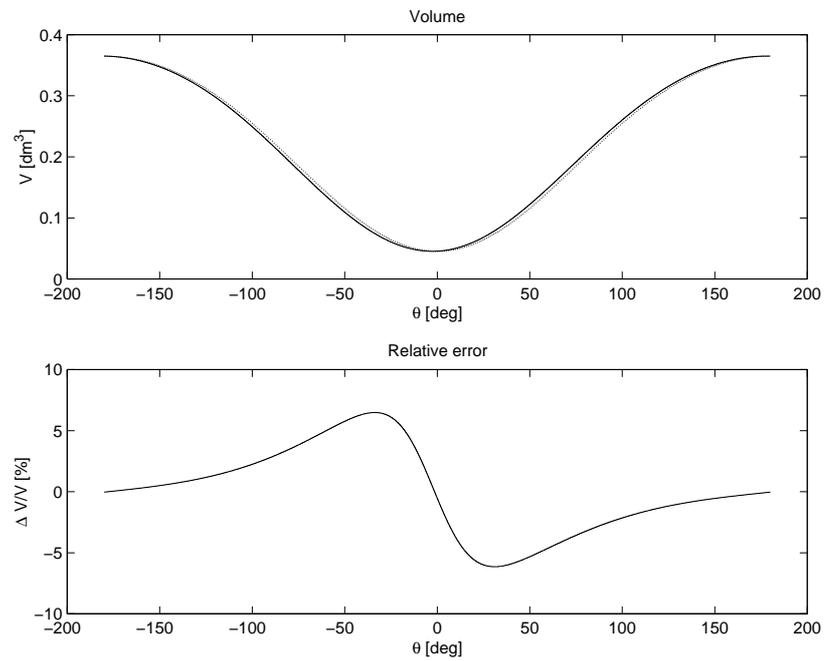


Figure 8: *Top:* Volume as function of crank angle at $v = 4^\circ$. The solid line is simulated with the SVC volume function and the dotted line simulated with a standard volume function. *Bottom:* Relative difference between the standard volume function and the SVC volume function, i.e. $\frac{V_{std} - V_{SVC}}{V_{SVC}}$.

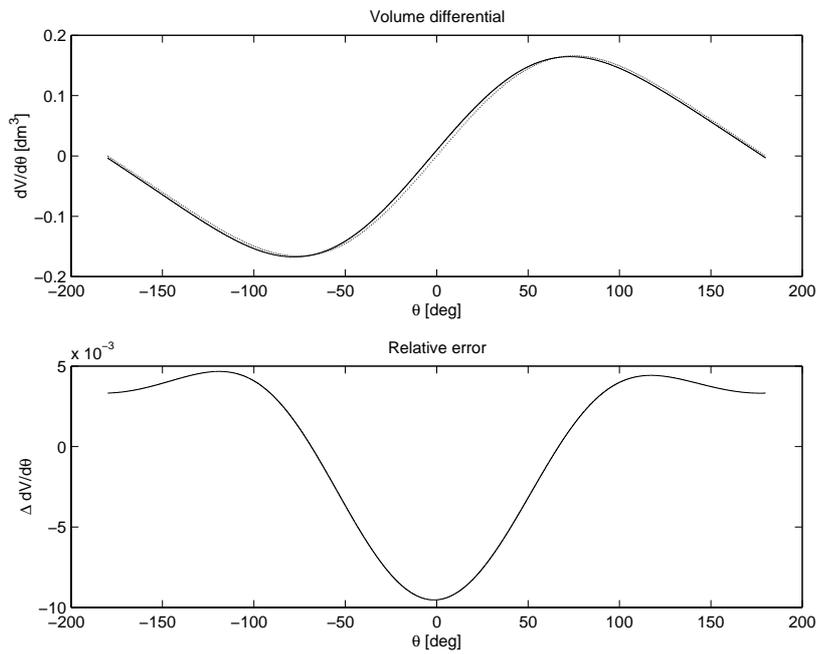


Figure 9: *Top*: Volume differential as function of crank angle at $v = 4^\circ$. The solid line is simulated with the SVC volume function and the dotted line simulated with a standard volume function. *Bottom*: Difference between the standard volume function and the SVC volume function, i.e. $\frac{V_{std} - V_{SVC}}{V_{SVC}}$

angle input to the standard volume function can then be adjusted according to:

$$\theta' = \theta - \hat{\theta}_{TDC}$$

The result from a simulation with such a crank angle input is shown in Figure 10. As before, the simulation is done at a tilt angle of 4° . No changes are done on the crank angle input to the SVC volume function. As can be seen, the error caused by using the simple model is much reduced. The relative error in volume does not exceed 0.6% and the maximum error in $\frac{dV}{d\theta}$ is reduced with a factor four.

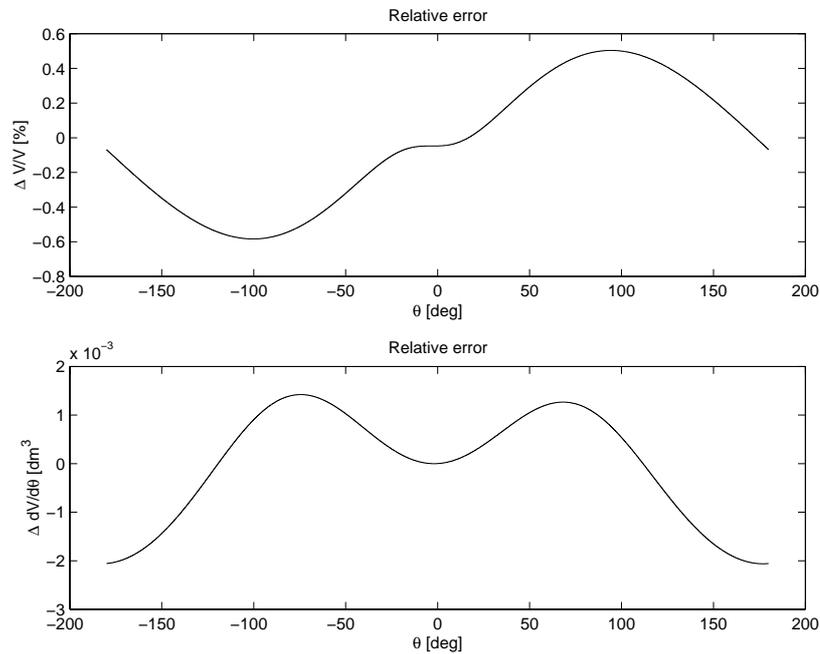


Figure 10: The crank angle degree has been adjusted to compensate for the deviation in TDC from $\theta = 0$, when simulating with the standard volume function. *Top*: Relative difference in volume between the standard volume function and the SVC volume function. *Bottom*: Difference in volume differential between the standard volume function and the SVC volume function.

7.2 The effect of pin-off

Even when the engine top is not tilted, the cylinder is not centered above the crank axis. There is a pin-off between the cylinder and the crank axis. This is very common in modern engines.

The effect of the pin-off is normally neglected when calculating the cylinder volume as function of crank angle, since it makes the function more

complicated. In figure 11 it is shown how much the pin-off effects the volume. The 'maximum relative error' is the maximum relative deviation between the SVC volume function and the standard volume function at a tilt angle of zero degrees. The crank angle input to the standard volume function has been adjusted for the offset in top dead center, and the compression ratio is determined for each pin-off. The maximum relative error is a measure of how much the shape of the curve is changed when there is a pin-off. The pin-off of the SVC engine is 2.2 [mm], which is 1.09% of the length of the crank rod plus the piston-pin. This means that the maximum error caused by not including the pin-off in the model but still compensating for the change in TDC is 0.29%.

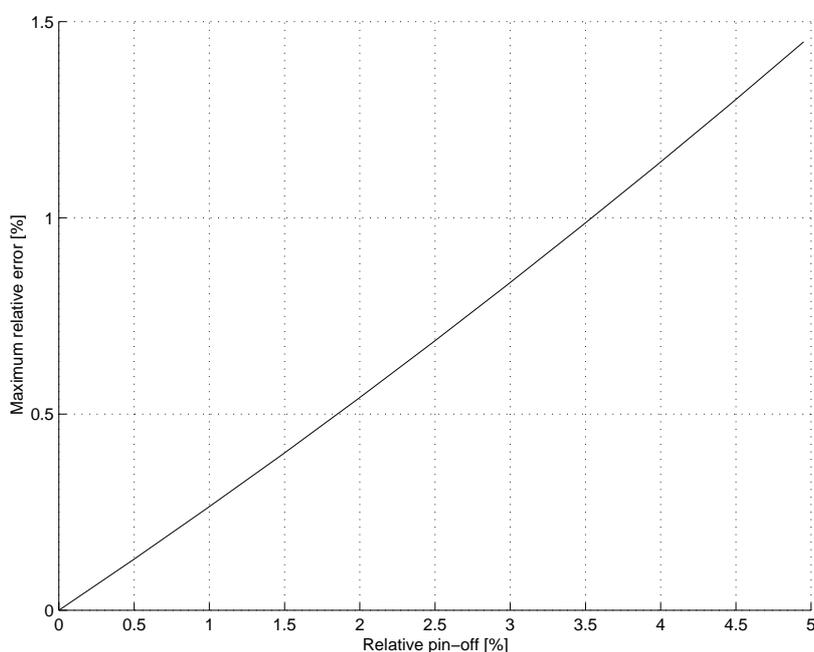


Figure 11: The relative error in volume at no tilt caused by neglecting the effect of pin-off. Relative pin-off is expressed in percentage of piston pin plus crank rod, i.e. $\text{relative pin-off} = 100 \cdot \frac{\text{pin-off}}{l+a}$.

8 Conclusions

Since the cylinders are not centered above the crankshaft and are often tilted, volume calculations with the standard cylinder volume function will not give accurate results. Comparing the standard volume function with the SVC volume function at a tilt angle of 4° , shows that the relative error is as big as 6% at some crank angles. This is due to the different shape

of the volume curve, the change in position of BDC, and most importantly the change in position of TDC. By adjusting the crank angle argument with the TDC offset, the standard volume function can be used with good result. The maximum relative error in volume will then be about 0.5%, and the error in volume differential will be reduced with more than a factor 4.

The pin-off has a noticeable effect on the cylinder volume. Neglecting the pin-off in the SVC function but adjusting for the change in TDC causes a maximum relative error of 0.29% at a tilt angle of zero degrees.

A.2 SVCvolume.m

```
function [out1,out2] = SVCvolume(arg1,arg2,choice)
%
%
%   SVCvolume
%   -----
%
%   [out1,out2] = SVCvolume(arg1,arg2,choice)
%
%   SVCvolume calculates the volume and its differential,
%   compression ratio and clearance volume or top and
%   position of bottom dead center a SVC engine. The
%   function uses a global variable ENGINE. If ENGINE is
%   not predefined when the function is called, ENGINE is
%   initialized by a call to SVCdata.
%
%
%   Calculate volume as function of crank angle:
%
%   [V,dV] = SVCvolume(crankangle,tiltangle)
%           crankangle may contain a vector
%           tiltangle should be a scalar
%
%
%   Calculate compression ratio and clearance volume as
%   function of tilt angle:
%
%   [rc,Vc] = SVCvolume([],tiltangle,'rc')
%           tiltangle may contain a vector
%
%
%   Calculate top dead center and bottom dead center as
%   function of tilt angle:
%
%   [TDC,BDC] = SVCvolume([],tiltangle,'tdc');
%           tiltangle may contain a vector
%
%
%   See also stdvolume SVCdata
%
%
```

```

global ENGINE
persistent Vc Pomax ang name
kf = pi/180;
if isempty(ENGINE)
    SVCdata;
end

if nargin<2
    disp('Error: Too few arguments to SVCvolume');
    out1 = [];
    out2 = [];
    return;
end
if nargin==2
    theta = arg1;
    v      = arg2;

    if isempty(ang)|any(size(ang)~=size(v))|any(size(Vc)~=size(v))|...
        ~strcmp(name,ENGINE.name)
        [Pomax,Vc] = comp(v);
        ang = v;
        name = ENGINE.name;
    elseif ang~=v
        [Pomax,Vc] = comp(v);
        ang = v;
    end

    [Po,dPo] = pointo(theta,v*ones(size(theta)));
    V = Vc + pi*ENGINE.B^2/4*(Pomax-Po);
    dV = -pi*ENGINE.B^2/4*dPo;
    out1 = V;
    out2 = dV;
else
    if strcmp(choice,'rc');
        v = arg2;
        [junk,Vc,rc] = comp(v);
        out1 = rc;
        out2 = Vc;
    elseif strcmp(choice,'tdc');
        v = arg2;
        out1 = tdc(v);
        out2 = bdc(v);
    else

```

```

        disp('Error: No match for choice in SVCvolume');
        out1 = [];
        out2 = [];
        return;
    end
end

```

```

function [Pomax,Vc,rc] = comp(v)
    global ENGINE
    persistent Vc0 Pomax0 ang name

    if isempty(ang) | any(size(ang)~=size(v))|~strcmp(ENGINE.name,name)
        [Vc0,Pomax0] = volume0;
        ang = v;
        name = ENGINE.name;
    elseif ang~=v
        [Vc0,Pomax0] = volume0;
        ang = v;
    end

    Pomax = pointo(tdc(v),v);
    Pomin = pointo(bdc(v),v);
    Vc     = Vc0 + pi*ENGINE.B^2/4*(Pomax0-Pomax);
    rc     = 1 + 1./Vc * pi*ENGINE.B^2/4.*(Pomax-Pomin);

```

```

function [Vc0,Pomax0] = volume0
    global ENGINE

    Pomax0 = pointo(tdc(0),0);
    Pomin0 = pointo(bdc(0),0);
    Vc0     = pi*ENGINE.B^2/(4*(ENGINE.rc0-1)) * (Pomax0-Pomin0);

```

```

function thmax = tdc(v)
    global ENGINE
    xprim = tan(v).*(ENGINE.y+ENGINE.r*sin(v))-ENGINE.x+ENGINE.r*cos(v);
    thmax = -v+asin(xprim/(ENGINE.l+ENGINE.a).*cos(v));
function thmin = bdc(v)

```

```

global ENGINE
xprim = tan(v).*(ENGINE.y+ENGINE.r*sin(v))-ENGINE.x+ENGINE.r*cos(v);
thmin = pi-v+asin(xprim/(ENGINE.l-ENGINE.a).*cos(v));

function [Po,dPo] = pointo(theta,v)
global ENGINE

xprim = tan(v).*(ENGINE.y+ENGINE.r*sin(v))-ENGINE.x+ENGINE.r*cos(v);
f      = ENGINE.a/ENGINE.l*sin(theta+v) - xprim/ENGINE.l*cos(v);
alpha  = acos(f)-v;
df     = ENGINE.a/ENGINE.l*cos(v+theta);
dalphi = -1./sqrt(1-f.^2).*df;

Po = 1./cos(v).*(-ENGINE.y - ENGINE.r*sin(v) + ENGINE.a*cos(theta) + ...
               ENGINE.l*sin(alpha)) ;
dPo = 1./cos(v).*(-ENGINE.a*sin(theta)+ENGINE.l*cos(alpha).*dalphi);

```

A.3 tilt.m

```

function v = tilt(rc)
%
%
%      tilt
%      ----
%
%      v = tilt(rc)
%
%      Tilt returns the tilt angle 'v' for a given compression
%      ratio 'rc'. The compression ratio should be in the range
%      8 to 14. Tilt uses interpolation to calculate the tilt
%      angle.
%
%      The function uses a global variable ENGINE. If ENGINE is
%      not predefined when the function is called, ENGINE is
%      initialized by a call to SVCdata.
%
%      See also SVCdata
%
%
kf = pi/180;

```



```

end
end

Vc=((B/2)^2)*pi*2*a/(rc-1);          % Clearance volume [m^3]

s1= sqrt(l^2 - a^2*(sin(theta)).^2); % Hjälpvariabel
s = a*cos(theta) + s1;              % Hjälpvariabel

V = Vc + pi*B^2/4*(l+a-s);
DV = pi*(B^2)/4*(a*sin(theta) + (a^2*sin(2*theta))./(2*s1));

```