SCORG^{TM} – Tutorial for Thermodynamic module using integrated GT-SUITE solver

SCORG is a tool for the design and analysis of rotary positive displacement machines including twin screw machines. It includes modules for grid generation; importing and editing rotor profiles; and multi-domain thermodynamic chamber module. For more information on the product please visit the website: www.pdmanalysis.co.uk or refer to documentation help.

GT-SUITE supplies a comprehensive set of component libraries which simulate the physics of fluid flow, thermal, mechanical, electrical, magnetic, chemistry, and controls. From those libraries, one can build accurate models of almost any engineering system, including vehicles, engines, drivelines, transmissions, general powertrains and mechanical systems, hydraulics, lubrication and friction, thermal management, cooling, chemistry, after treatment and much more.

Integration of the above softwares brings a new set of possibilities, allowing for multyphisics simulations.

This tutorial lists the steps for setting up and performing Thermodynamic calculation which could be used for performance prediction of oil free and oil injected screw compressors and expanders with SCORG and GT-SUITE. The user is expected to be familiar with screw machines. It is highly recommended that a user who attempts this tutorial study the books on the performance prediction methods for screw compressors[1][2]. This Tutorial should be studied alongside the SCORG^{TM} User Manual. Users are also expected to be familiar with GT-SUITE.

The steps explained in this tutorial are demonstrated for Windows 10, x64 bit OS. Refer to SCORG^{TM} Installation Guide V5.9 for the system and hardware requirements.

[1] N. Stosic, I.K. Smith, A. Kovacevic Screw Compressor Mathematical Modelling and Performance Calculation, Springer, UK 2005, ISBN-10 3-540-24275-9

[2] A. Kovacevic. N. Stosic, I.K. Smith, Screw Compressor Three Dimensional Computational Fluid Dynamics and Fluid Solid Interaction, Springer, 2006, ISBN 3-540-36302-5

Table of Contents

1 Introduction

Screw Compressors are rotary positive displacement machines. They can be oil-free or oil injected. Oil-free compressors require rotors to be synchronised by additional timing gears on the rotor shaft in order to maintain the contact-free operation. In the oil injected compressor one rotor drives the other through direct contact, Figure 1.1

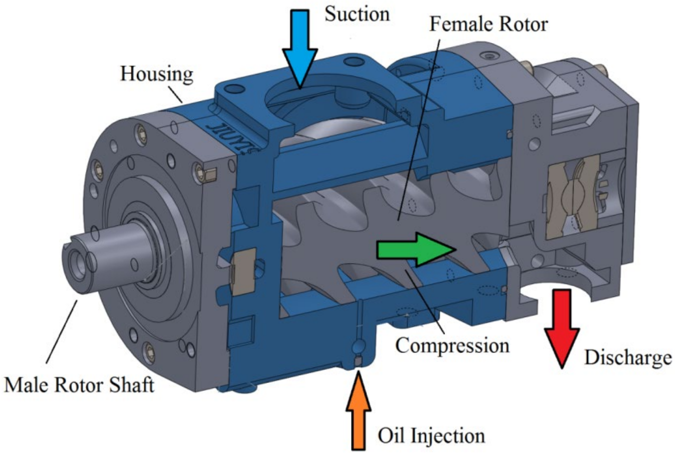


Figure 1.1 Oil injected twin screw compressor cross section

The screw compressor rotors are helically lobed gears with special rotor profile. Together with the casing, they form a closed interlobe space called the working chamber which changes the size and shape during the operation of the machine. The working chamber itself is periodically connected to the suction and discharge chambers through flow areas which vary with time both in shape and size. The schematic view of a screw machine (compressor, pump or a motor) is shown in Figure **1.2**.

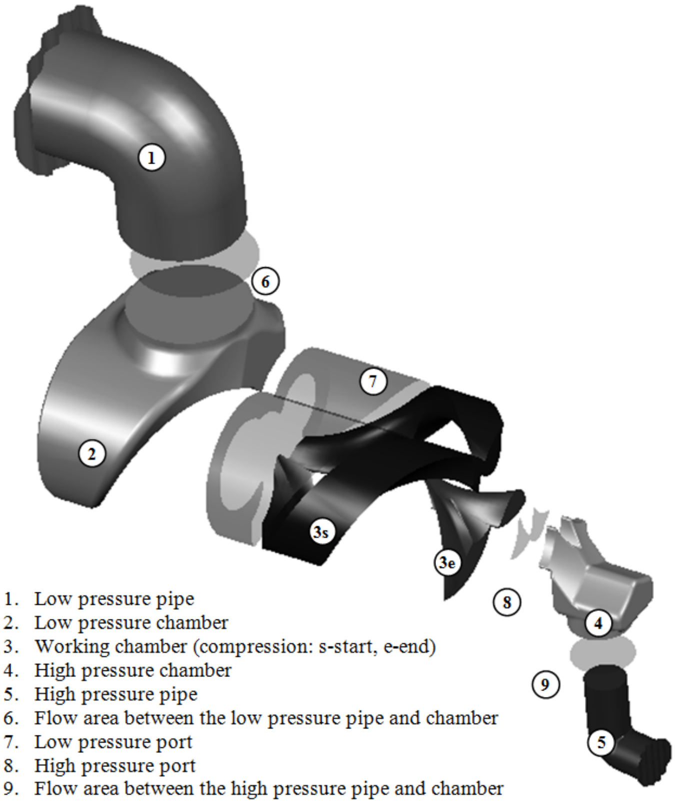


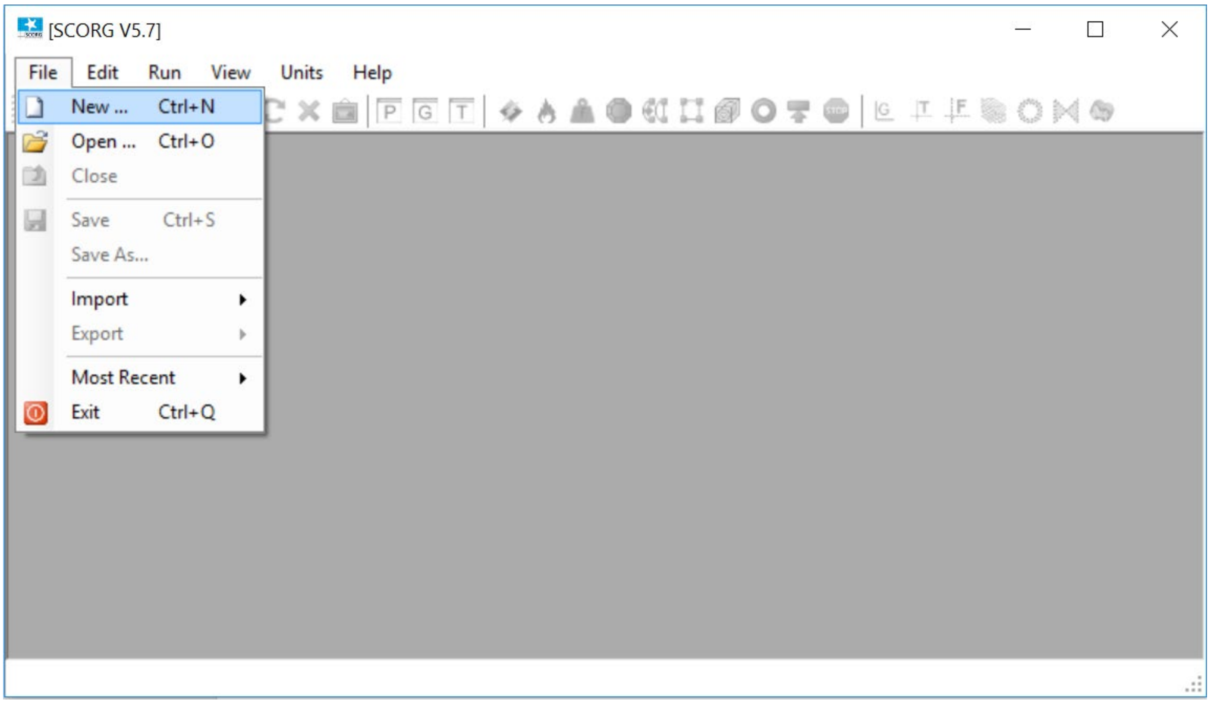
Figure 1.2 Configuration of a screw compressor

This Tutorial will provide a step by step guide to set up and execute a thermodynamic simulation of a typical twin screw compressor using the integrated GT-SUITE solver. An example of a dry air compressor with 3/5 lobe combination, L/D ratio of 1.6 and wrap angle 285° is used in the tutorial. The effect of oil injection will also be demonstrated.

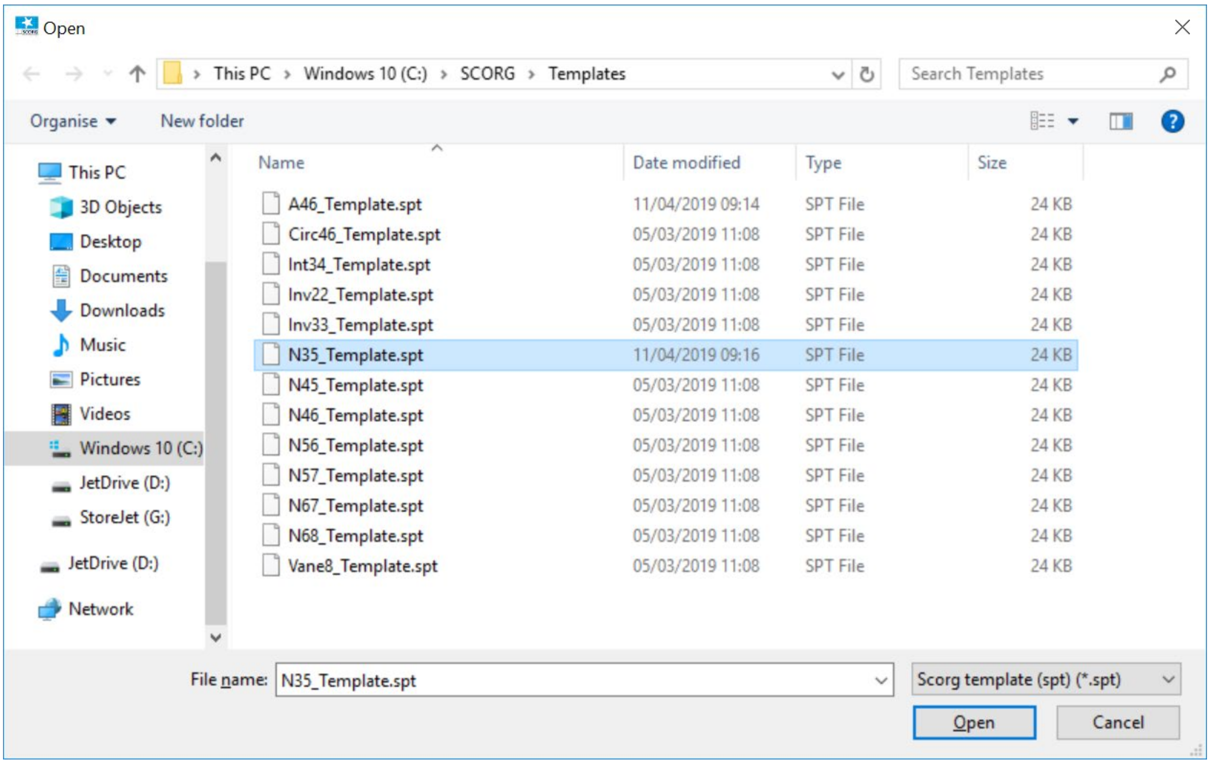
2 Setup the project

2.1 Start SCORG™ Project

- Launch SCORG™ on the Desktop.
- Select File → New

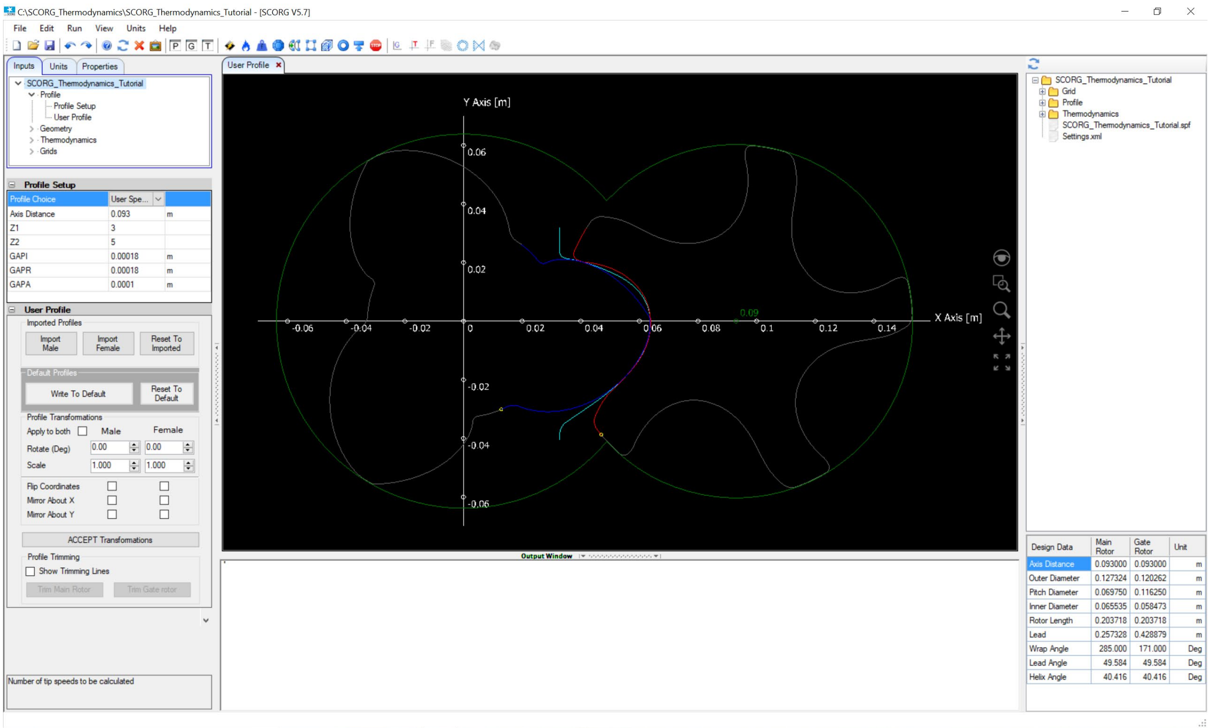


- Select N35_Template.spt → Open



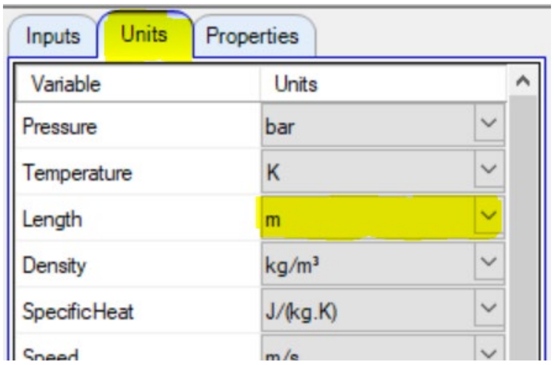
- Save the project in a new folder named SCORG_Thermodynamics→ SCORG_Thermodynamics_Tutorial.spf

- The GUI of SCORG™ in the figure below shows the main items of the front panel.

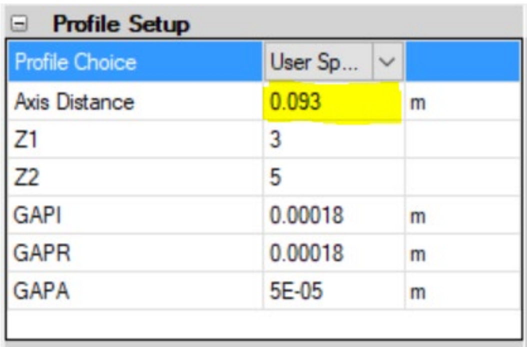


- Go to Help → Tutorials → Folder opens
- Copy the compressor rotor profile files → [*35MaleProfile_P1.dat* and *35FemaleProfile_P2.dat*]
- Paste these files in the working directory → SCORG_Thermodynamics

- Set Length Units to meters.

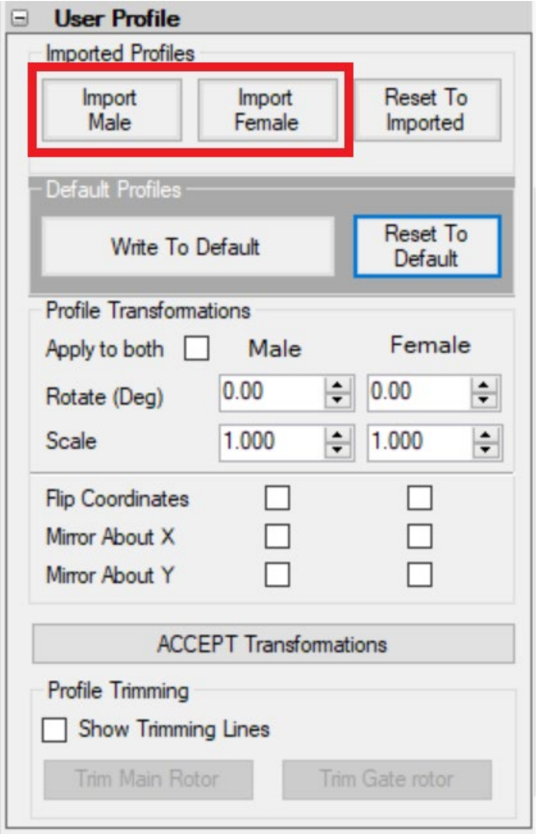


In Profile Setup, adjust Axis Distance to 93 mm.

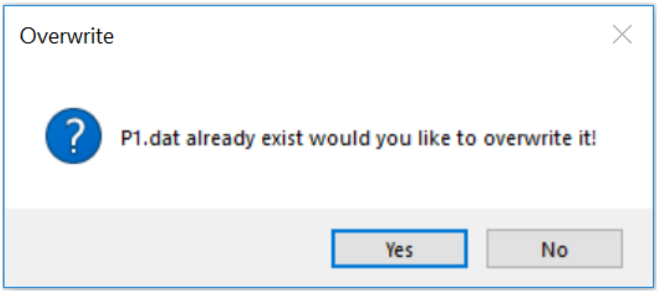


- Go to User Profile → Browse and Select the Male Rotor Profile from the working directory.

  35MaleProfile_P1.dat



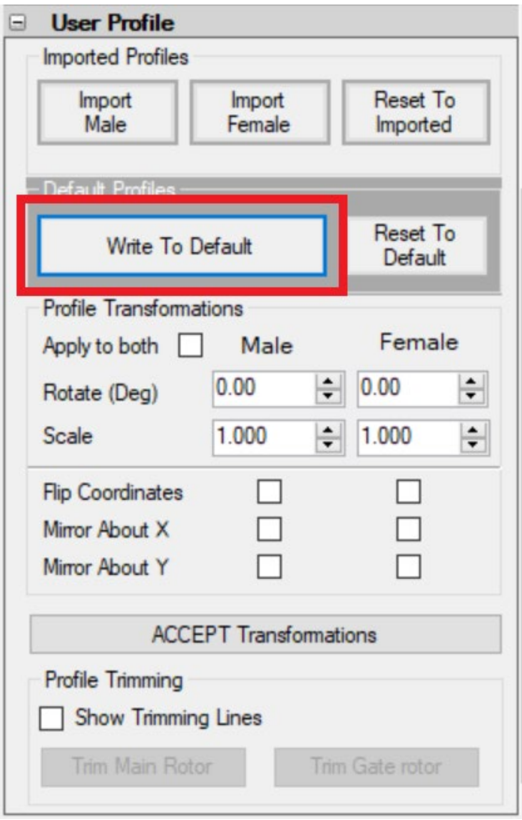
- Click 'Yes' to overwrite P1.dat.



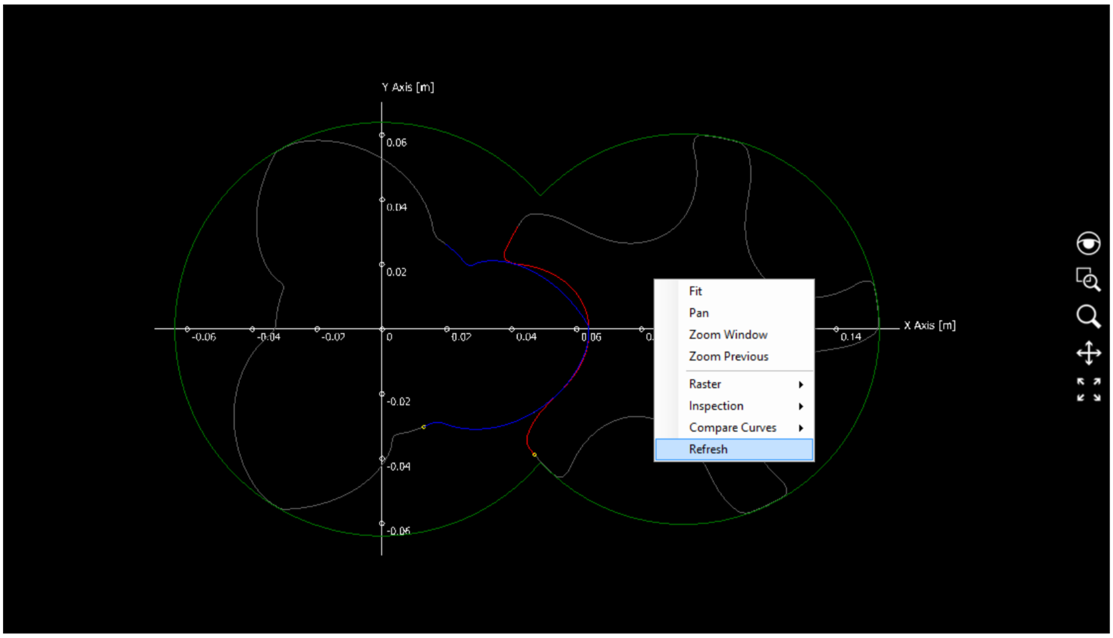
- Similarly, Select the Female Rotor Profile.

  35FemaleProfile_P2.dat

- Click Write To Default.



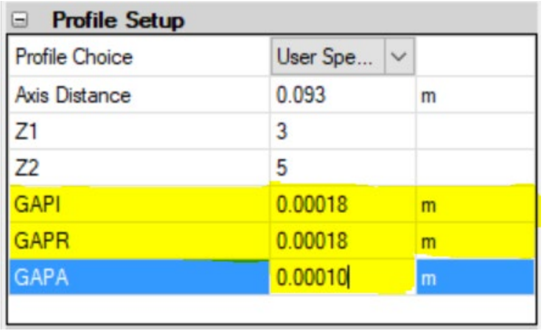
- Click the Right button and select Refresh to view new profiles.



- Inspect the Rotor Profile in the GUI for gaps in the tips, starting points of the profile indicated by the small yellow circles. For more information, please see Section 6.4 in the SCORG™ User manual.

2.2 Set Geometrical Clearances

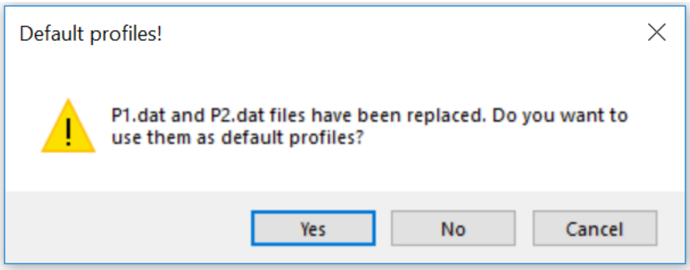
- Set the following Profile Parameters to get desired clearance size:



- Run Geometry calculation through the shortcut highlighted in the figure below

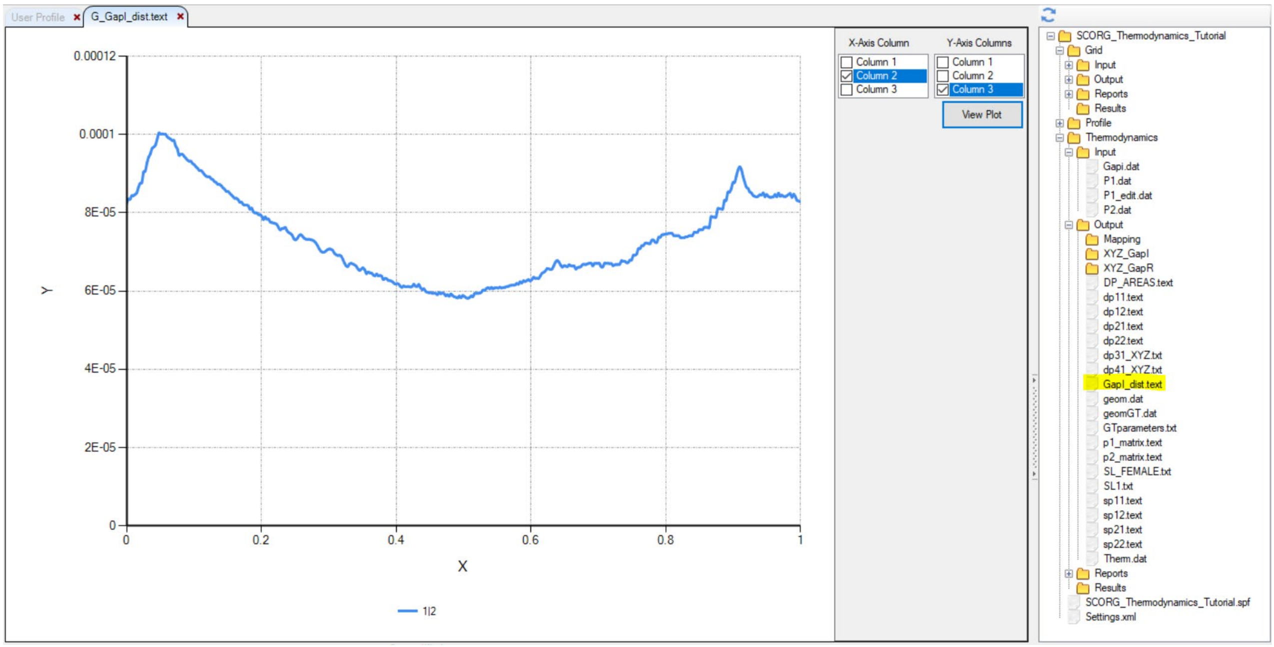
- Run Rack generation procedure by clicking on the Numerical rack shortcut button.

  This is required to inspect the profile and make any required corrections of the imported rotor profiles. You will receive the following message:



- Click on Yes to accept the correction of the profiles.

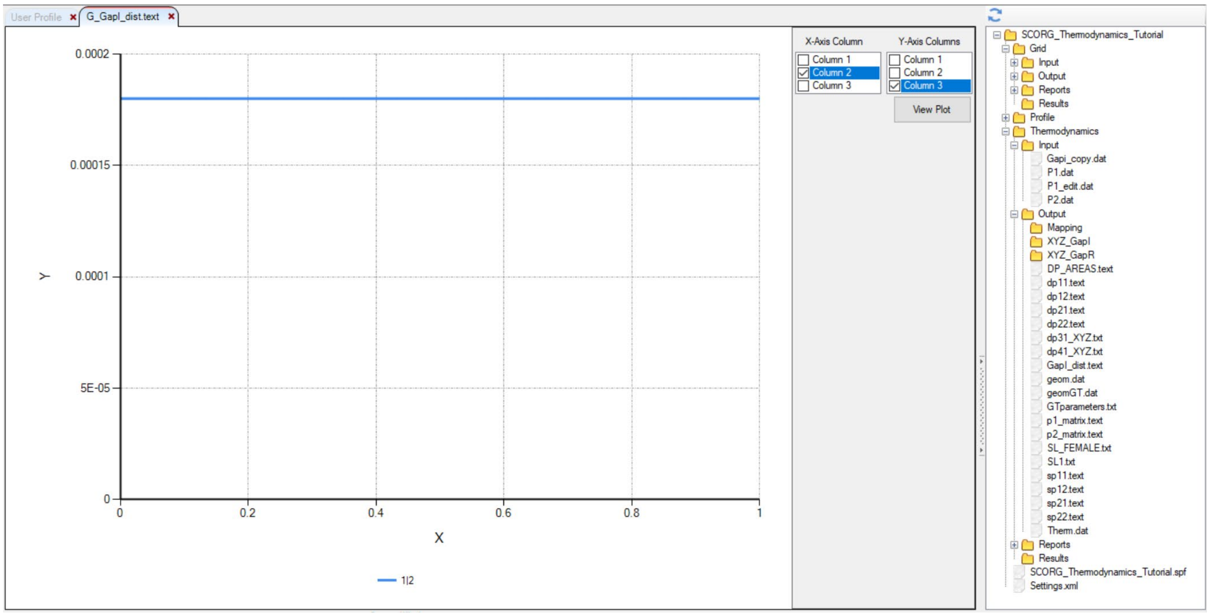
- Now you can inspect the Interlobe clearances which the imported profile will have with the given axis distance. To do that, click with the right mouse button on file Case->Thermodynamics->Output->GapI_dist.txt, select Graphical view and select columns 2 and 3 for X and Y axis respectively. The normal clearance distribution along the sealing line represented in the relative position from the beginning to the end of the profile is shown. In the diagram below, it is visible that the normal clearance varies from 0.06 mm to 0.1 mm in the given profile.



If you want to use this clearance for calculation of thermodynamic performance then set the GAPI value to 0.

- If you want to set Interlobe Clearance in thermodynamic through the Input value GAPI, then set up the GAPI to desired clearance value.

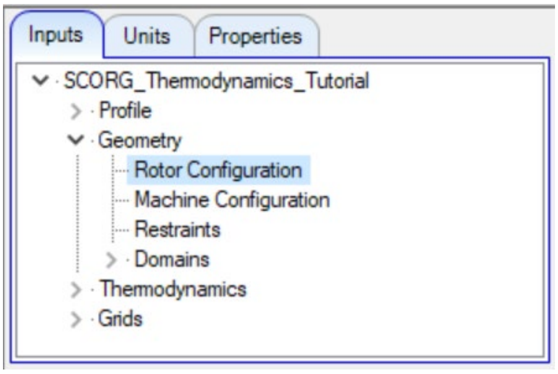
If you want to completely remove the clearance from the imported profile, then delete the file Case->Thermodynamics->Input->GapI.dat. Then recalculate Geometry and refresh the diagram. You should see the diagram below.



- Save the Project.

3 Set and calculate Geometry

In order to perform thermodynamic calculation and to obtain expected results, it is important to set up all geometry and operational inputs correctly. This will be adjusted through the Inputs window for Geometry.

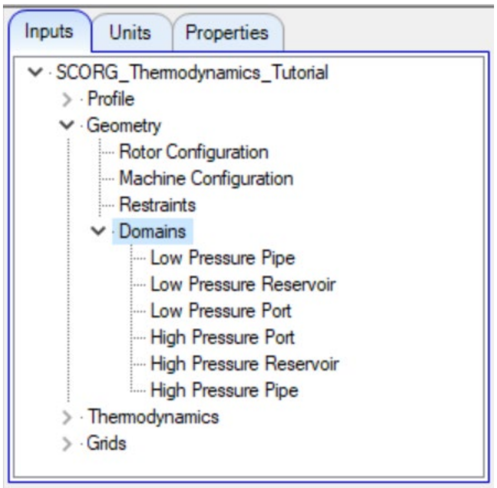


- Set values for Rotor Configuration and Machine Configuration as indicated below.

Rotor Configuration		
Relative Length	1.6	
Rotor Length	0.203718	m
Wrap Angle	285	Deg
Pitch Low Pressure Port	0	m
Pitch High Pressure Port	0	m
Rotor Pitch	Uniform	
Rotor Profile	Constant	
Main Rotor Centre X	0	m
Main Rotor Centre Y	0	m
Main Rotor Centre Z	0	m
Main Rotor Start Angle	0	Deg
Rotor Stage Number	0	
Gate Rotor Angular Position	0	Deg
Main Rotor Helix	Right	
Gate Rotor Position	Right	

Machine Configuration		
Machine Type	Screw Co...	
N Gate	1	
Compression Start	0	Deg
Compression End	161.792	Deg
Volume Index	1.8	
Angle of Radial Discharge...	0	Deg
E Rotor	211	GPa
αL Rotor	1E-05	m/m/K
E Casing	211	GPa
αL Casing	1E-05	m/m/K
Wall Roughness	0	m

- The next geometry setup is related to set the size of flow domains and passages shown in Figure 1.2.



The volumes of these domains and flow areas between them are set through the menu shown in the figure above.

The domains in the Inputs are also shown in Figure 1.2 with the following numbers:

- Low pressure Pipe — Domain 1
- Low Pressure Reservoir — Domain 2
- High Pressure Reservoirs — Domain 4
- High Pressure Pipe — Domain 5

All these volumes are set by the equivalent diameter and length of each of these domains.

Flow areas between these domains in reference to Figure 1.2 are defined in the following way:

- The area 6 between the Low pressure pipe (1) and Low pressure Reservoir (2) is defined by the Diameter of the Low Pressure Pipe
- The area 9 between the High Pressure Reservoir (4) and High Pressure Pipe (5) is defined by the Diameter of the High Pressure Pipe
- The area between the Low Pressure Reservoir (2) and the Working Chamber (3) is called Low pressure Port. It is calculated by the Geom program as described in the User Manual while in the Inputs it is only selected if the port is Axial, Radial or both. The size of the port is defined by the Compression Start Angle in Machine Configuration.
- The area between the Working Chamber (3) and the High Pressure Reservoir (4) is called High Pressure Port. It is calculated by the Geom program as described in the User Manual. In Inputs, it is only selected as the Axial, Radial port or both. The size of the port is defined by the Compression End Angle in Machine Configuration which directly depends on the Volume Index.

- Set values of the flow domains as shown below.

Low Pressure Pipe		
Diameter	0.1	m
Length	0.2	m

Low Pressure Reservoir		
Diameter	0.1	m
Length	0.1	m

⊞ Low Pressure Port

⊞ High Pressure Port

High Pressure Reservoir		
Diameter	0.075	m
Length	0.075	m

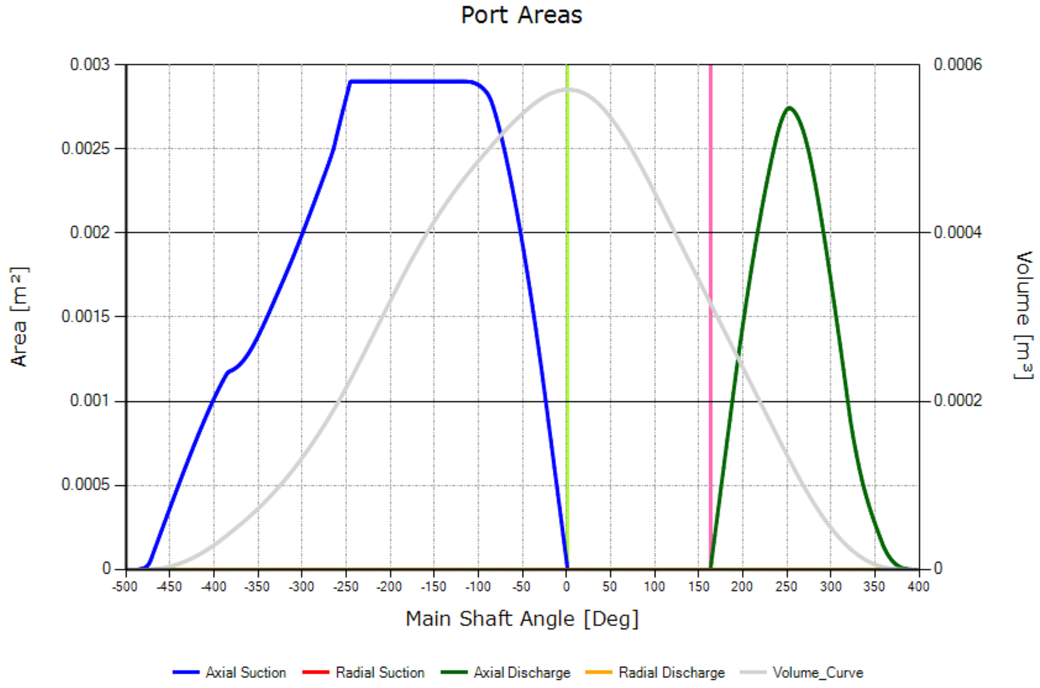
High Pressure Pipe		
Diameter	0.05	m
Length	0.2	m

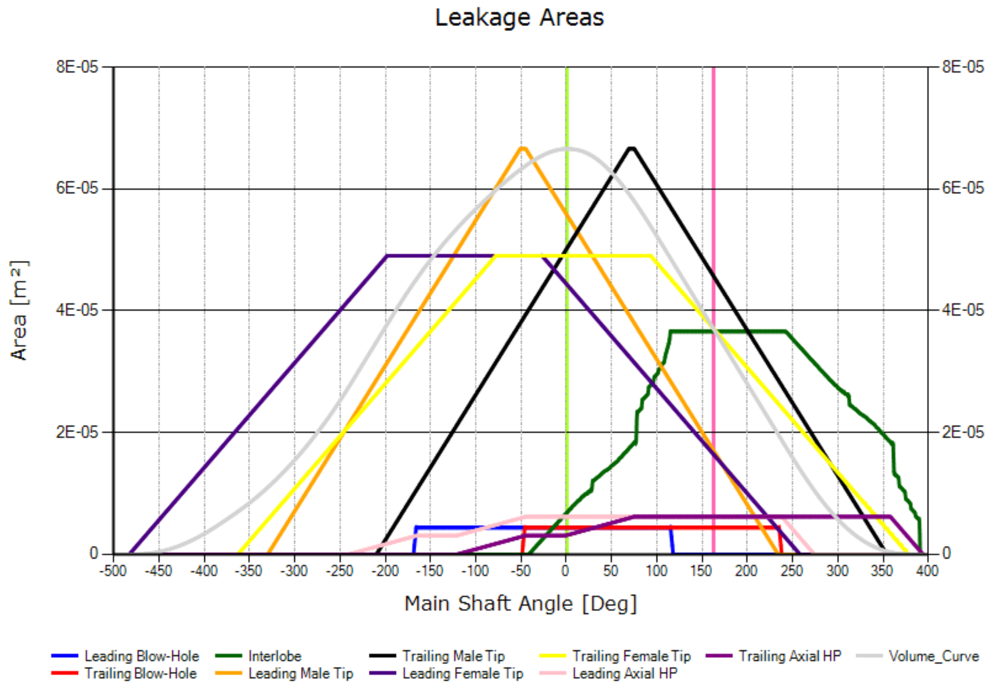
Low Pressure Port		
Port Type	Axial	
Depth Radial	0.008	m
Circular Divisions	100	
Radial Divisions	8	
Depth Axial	0.009	m
Angle Radial End Face	45	Deg
Length Radial	0.021	m
Axial Clearance	0.0002	m
Orthogonalisation Factor	1	

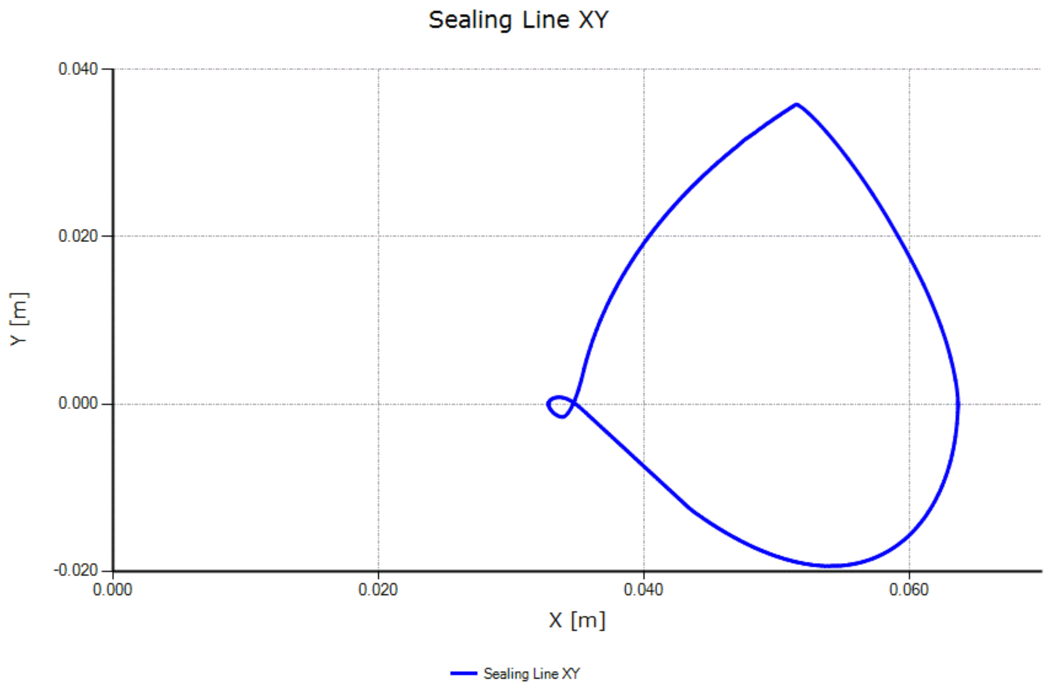
High Pressure Port		
Port Type	Axial	
Inner Circle Diameter	1	
Circular Divisions	20	
Radial Divisions	20	
Z Divisions	5	
Length	0.016	m
Axial Clearance	0.00013	m
Orthogonalisation Factor	0.6	

- Calculate Geometry by clicking on the shortcut button for geometry calculation.

- Inspect geometry diagrams.


Port Areas
Area [m²]
Volume [m³]
Main Shaft Angle [Deg]
Axial Suction
Radial Suction
Axial Discharge
Radial Discharge
Volume_Curve


Leakage Areas
Area [m²]
Volume [m³]
Main Shaft Angle [Deg]
Leading Blow-Hole
Trailing Blow-Hole
Interlobe
Leading Male Tip
Trailing Male Tip
Leading Female Tip
Trailing Female Tip
Leading Axial HP
Trailing Axial HP
Volume_Curve



Port Areas – The diagram shows the area of the Suction and Discharge Ports as a function of the rotation angle as well as any other ports if they exist, such as oil injection port or economiser port. The diagram also shows the Volume curve and two vertical lines demonstrate the start and end of the compression process.

Leakage Areas – The diagram shows the flow area through leakage paths as a function of the main shaft angle. These include leakage areas of the inflow and outflow leakages.

The inflow leakage paths are those through which fluid leaks in the working chamber.

- Leading blowhole area, leading male and female tip leakage area (radial leakage) and leading axial gap area

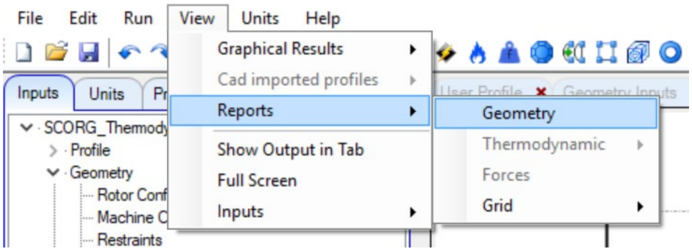
The outflow leakage paths through which fluid leaks from the working domain are:

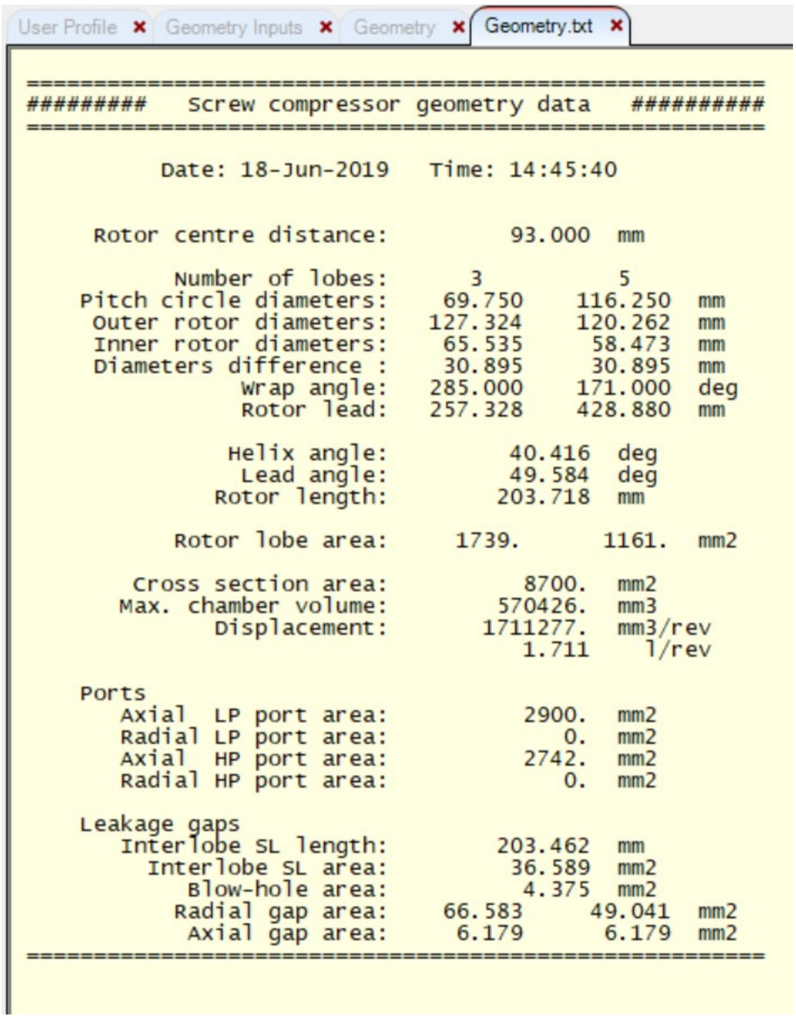
- Trailing blowhole area, trailing male and female tip leakage area (radial leakage), interlobe gap area and trailing axial gap area.

Sealing line – The diagram shows the sealing line in three coordinate planes, XY, YZ and ZX.

The influence of the change in clearances on the performance of the machine will be evaluated in the next Section.

- Inspect geometry report.





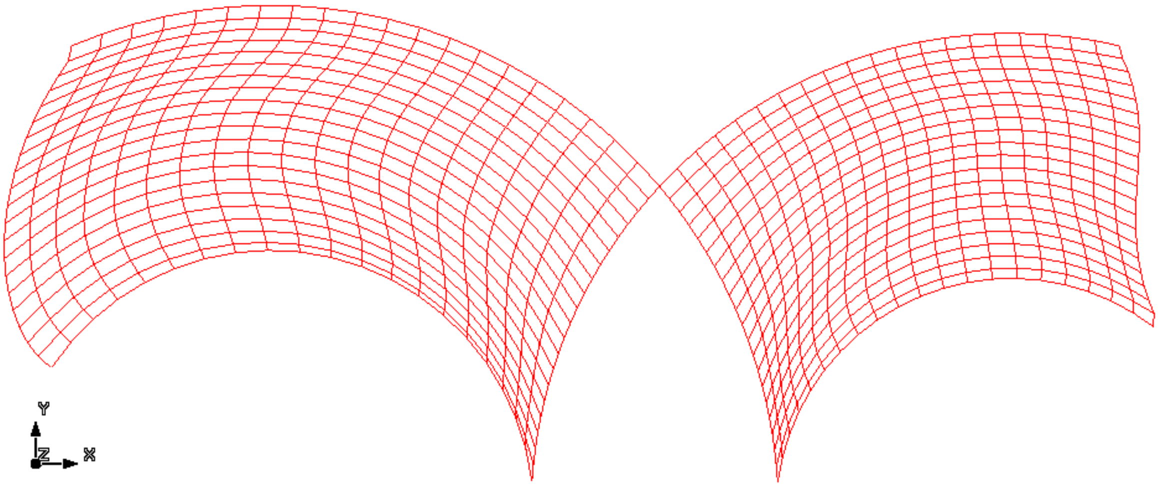

```
=========================================================
#########    Screw compressor geometry data    ##########
=========================================================

          Date: 18-Jun-2019   Time: 14:45:40


     Rotor centre distance:         93.000  mm

           Number of lobes:      3         5
    Pitch circle diameters:   69.750   116.250  mm
     Outer rotor diameters:  127.324   120.262  mm
     Inner rotor diameters:   65.535    58.473  mm
     Diameters difference :   30.895    30.895  mm
                Wrap angle:  285.000   171.000  deg
                Rotor lead:  257.328   428.880  mm

               Helix angle:         40.416  deg
                Lead angle:         49.584  deg
              Rotor length:        203.718  mm

           Rotor lobe area:    1739.      1161.   mm2

        Cross section area:          8700.  mm2
       Max. chamber volume:        570426.  mm3
              Displacement:       1711277.  mm3/rev
                                    1.711     l/rev

    Ports
       Axial  LP port area:          2900.  mm2
       Radial LP port area:             0.  mm2
       Axial  HP port area:          2742.  mm2
       Radial HP port area:             0.  mm2

    Leakage gaps
       Interlobe SL length:        203.462  mm
         Interlobe SL area:         36.589  mm2
            Blow-hole area:          4.375  mm2
           Radial gap area:   66.583    49.041  mm2
            Axial gap area:    6.179     6.179  mm2
=========================================================
```

The values shown in two columns relate to Male (left) and Female rotor (right).

- View the axial discharge port.

  The shape and the size of the discharge port are defined by the Compression End angle which is in turn defined by the Volume Index Vi. In order to inspect the shape and size of the discharge port please calculate grid for the discharge port using highlighted shortcut button below and then display the port mesh using the shortcut button shown in the rectangle.

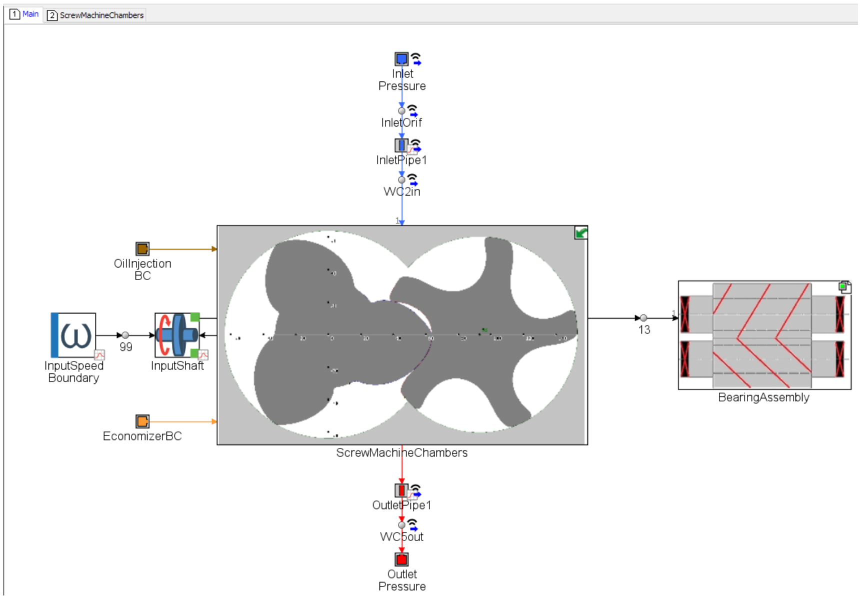
The shape and size of the port are displayed below. It will later be shown how it changes with the change in Vi.

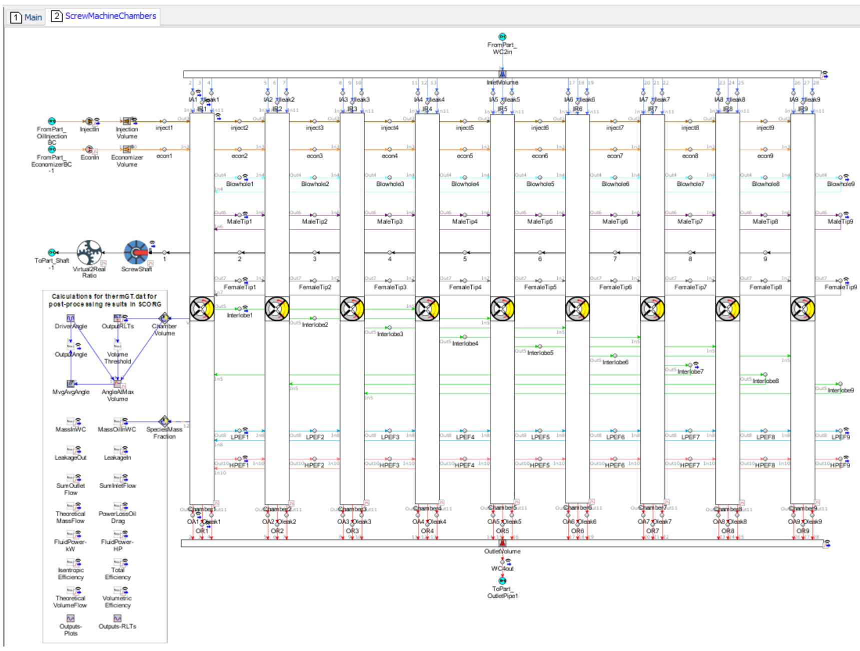


4 Set and calculate Thermodynamics with GT-SUITE

Once the geometry of the compressor is correctly defined, it is possible to perform the thermodynamic calculation. The objective of this calculation is to determine the flow rate and power of the specified compressor operating at certain operating conditions and with a certain working fluid.

Predefined model templates are used to perform thermodynamic calculations. Selection of the template is done automatically and is based on the configuration of the specific machine. Template files are saved in SCORG installation folder > GT > GTtemplates (Usually: C:\SCORG\GT\GTtemplates). Sample model project is shown below.



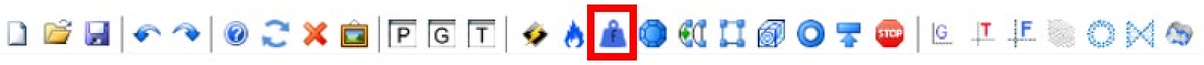


There are two tabs present in the GT-SUITE model called **Main** and **ScrewMachineChambers.** Their contents can be viewed by switching between the Main and

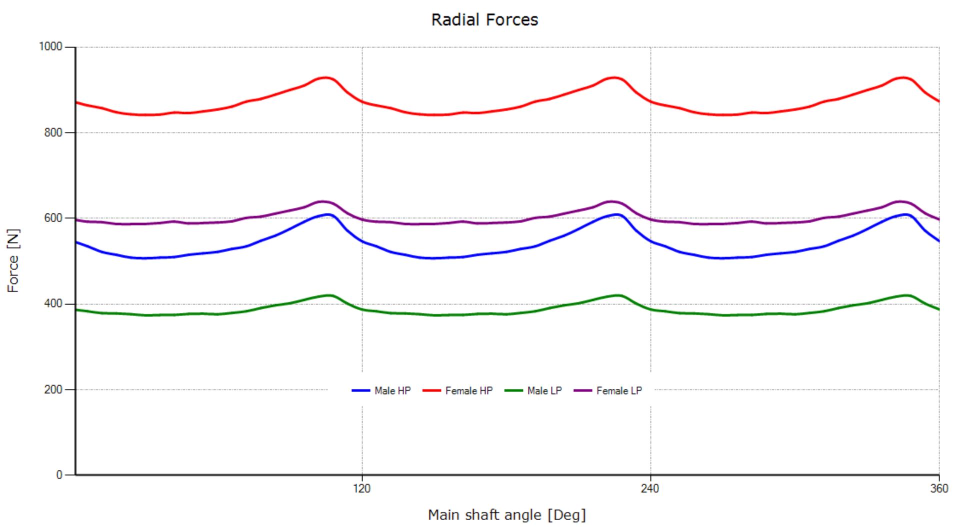
ScrewMachineChambers tabs at the top left of the images shown. Alternatively, it is possible to double-click on the image of the rotors to see the contents of the ScrewMachineChambers subassembly. The contents of this main model can be modified such as including the piping at the inlet, outlet and optionally, the injection and economizer ports.

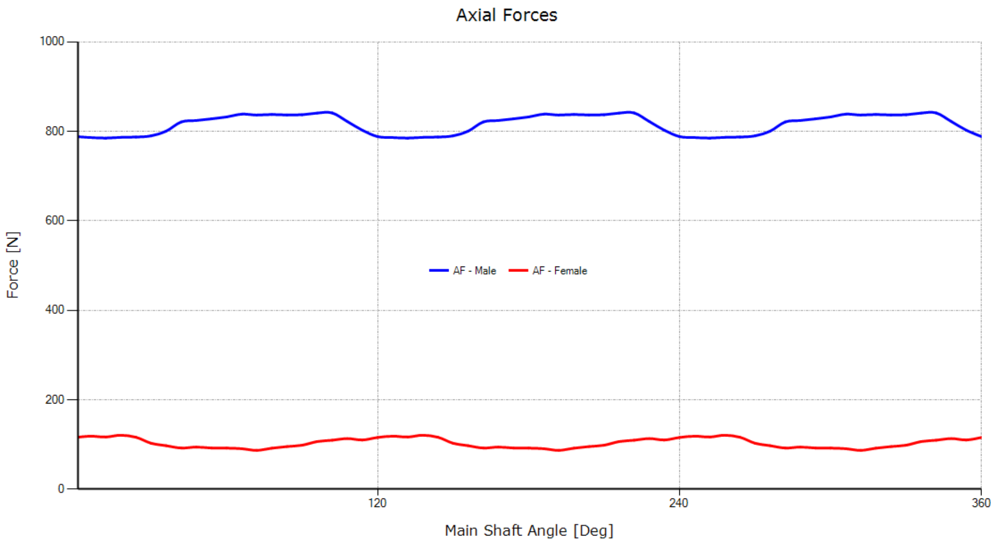
There is also an additional block (External Subassembly) in the Main tab called "BearingAssembly". This points to one of three external subassemblies (.gtsub file extension) that have been included with the installation – RollerBearingsAssy.gtsub (contains roller bearings on the shaft), JournalBearingsAssy.gtsub (contains journal bearings on the shaft), and NoBearingsAssy.gtsub (no bearings modeled on the shaft). Depending on the "Bearing Type" setting under Inputs -> Bearings and Seals in SCORG, one of either RollerBearingsAssy or JournalBearingsAssy will be chosen. If no bearings are desired, all of the 4 input parameters below "Bearing Type" can be set to 0. This will automatically select the NoBearingsAssy within the main GT model.

The SCORG Thermodynamic Calculation must be run first after which the Force calculation must be run to generate two additional text files containing the profiles for the radial and axial X and Y forces vs shaft angle for the male and gate rotors. Following this, the GT-SUITE Thermodynamics Calculations can be run.



The generated force profiles can be viewed by clicking on the Force diagrams button.





Calculation of performance takes place in the SCORG installation folder > GT folder by default. However, the location of the model can be modified under Inputs -> Thermodynamic Controls -> GT Case Folder as shown below.

Thermodynamic Controls		
Speed loop	1	
Psuc loop	1	
Pdis loop	1	
Convergence loop	20	
ΔWtip	5	m/s
ΔPsuc	0	Pa
ΔPdis	1	Pa
ΔTevp	5	K
ΔTcon	5	K
Clearance adjustment	No	
Short report settings	Settings...	
Thermodynamic solver	GT_SU...	
GT Case Folder	C:\SCORG...	

Input files (discussed below) and the template files (ScrewMachine-#chambers.gtm and one of the three bearing subassembly files) are copied from their original folders to this folder. The output of the simulation is saved in the selected folder and later copied to the SCORG installation folder > GT.

Input files are first generated in the GT Case Folder and copied to the SCORG installation folder > GT. These include:

GeomGT.txt – contains geometry values for volume, port areas, leakage flow areas

GTParameters.txt – contains parameters required for setting up and running the case in GT-SUITE.

Forces_R1_GT.txt – contains the radial and axial forces vs shaft angle for the male rotor which are referenced by the GT-SUITE model to consider bearing/seal/drag frictional power losses.

Forces_R2_GT.txt – contains the radial and axial forces vs shaft angle for the gate rotor which are referenced by the GT-SUITE model to consider bearing/seal/drag frictional power losses.

GT.bat – batch file created for each case individually to select an appropriate template and run the case.

The output files are as follows:

thermGT.trn – contains result data in a tabular form. Each column represents different value as specified in the first row. This file is later transformed into Therm.dat and copied to the Case folder > Thermodynamics > Outputs to be used for constructing diagrams in SCORG.

Thermo_Normal_GT.trn – contains integral results that characterize operation of the machine.. The results are available in the form of a short Thermodynamic report in the Case folder > Thermodynamics > Reports

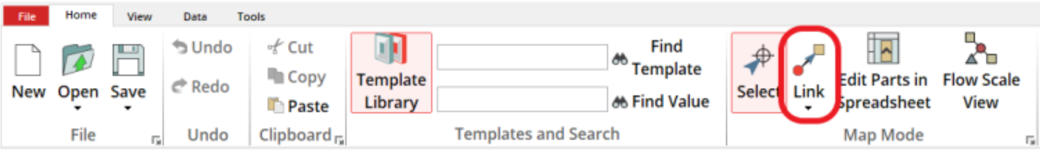
***.glx** – name differs depending on a template used. GT-POST file with all the results. Section 4.8 describes how to use it.

4.1 GT template selection

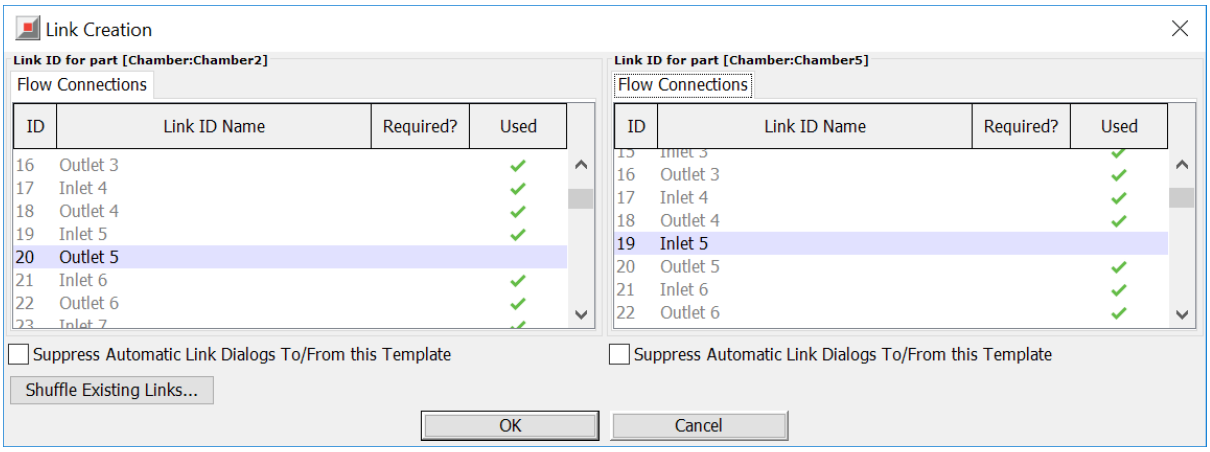
The template file is selected automatically using the batch file generated in the SCORG geometry calculation process.. Templates are available for the most common configurations of machines. In case of unusual combination of lobes in the male and female rotors, some modifications may required.

When running a calculation with GT-SUITE a file with an appropriate number of working chambers will be selected and called. The number of chambers is calculated as a multiplier of a number of male lobes and a number of full rotations required to complete a cycle, i.e. for a compressor with 4 lobes male rotor, completing the cycle within 3 interlobe rotations, 12 chamber model will be used. While there are several templates available, the user may pay close attention to the models where different configurations will produce the same number of the working chambers, i.e. the machine with 3 male lobes and 4 interlobe rotations will also use the 12 chamber model. In this case, some modification to interlobe leakage links may be required. The number of interlobe rotations required to complete a cycle depend on wrap angle of the machine. For standard screw compressors/expanders, the number of required interlobe rotations is usualy 3.

A general rule of linking chambers with the interlobe flow is to connect every N chamber to chamber N + #_male_lobes. If any change is needed it can be done by removing the existing leakage links and creating new ones with the **Link** tool.



When connecting chambers specific ports must be used. For chamber N, **Outlet 5** is selected and for chamber N + #_male_lobes **Inlet 5** is supposed to be chosen.

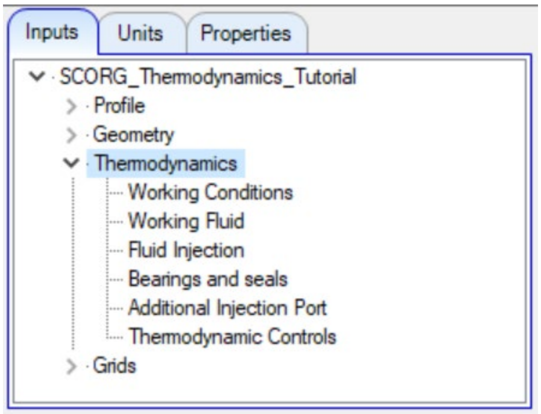


Once interlobe leakage links are correctly modified save the template and continue with setting up the simulation. It is advised to keep the copy of the original template file.

NOTE: For standard screw machines, none of modifications are required and the performance can be directly calculated from SCORG and results can be also presented in SCORG GUI.

4.2 Thermodynamics Inputs

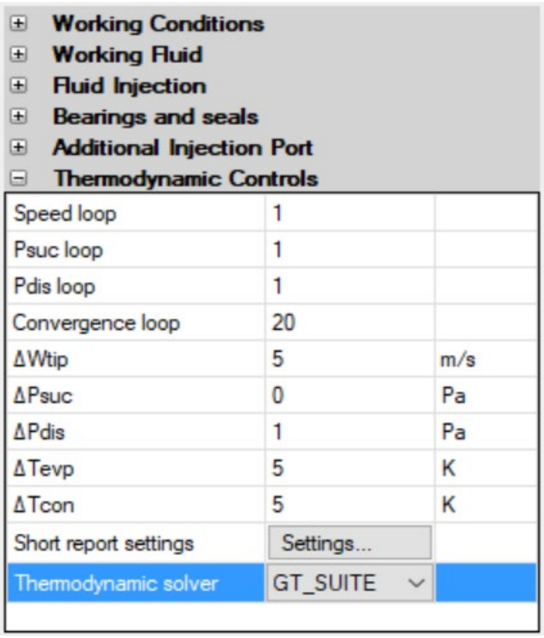
The setup for Thermodynamic calculations is performed through the Input controls shown in the control window below.



The controls are divided into 6 categories:

- Working conditions
- Working Fluid
- Fluid injection
- Bearing and seals
- Additional Injection Port
- Thermodynamic controls

- Thermodynamic controls



Select Thermodynamic Solver to GT-SUITE. Other controls are used only for calculations with SCORG solver and can be omitted.

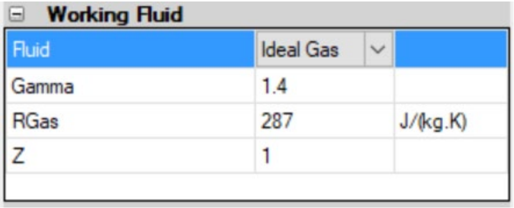
After selecting GT_SUITE recalculation of geometry is needed. During this process additional following files are created in the Case folder > Thermodynamics > Output folder:

GeomGT.txt – equivalent to Geom.dat, used in GT-SUITE to set the geometry of the machine. This file is extended to provide data for a complete number of full interlobe rotations required to complete the cycle of the machine..

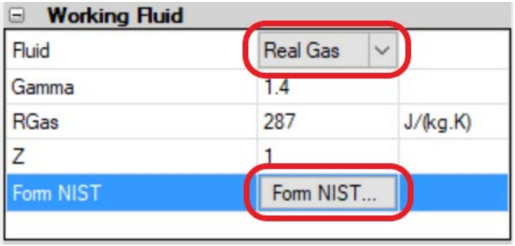
GTparameters.txt – file containing all the required parameters to set the case in GT-SUITE. This is discused later in this tutorial.

GT.bat – batch file stored in SCORG Installation folder> GT, it is used to call the GT-SUITE with the appropriate template file.

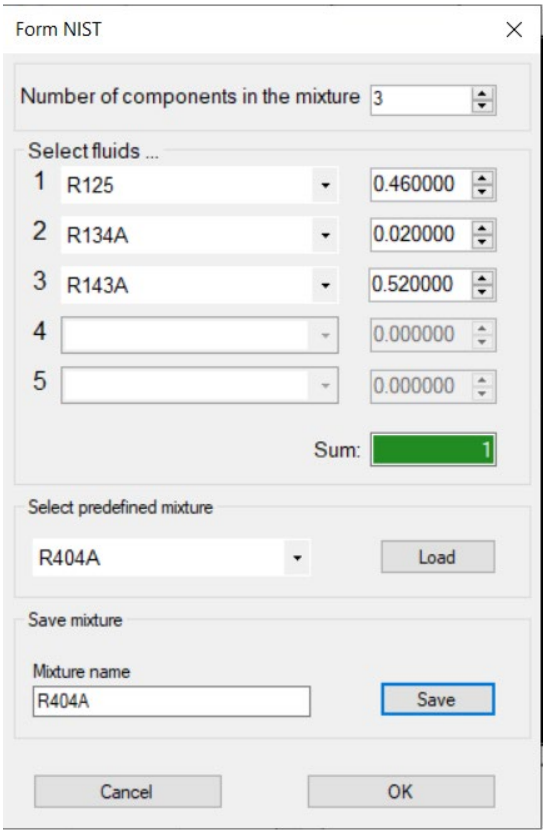
- Working Fluid



The working fluid can be an ideal or real gas. In this example, the ideal gas will be used. The values in the window on the left are values for air.



When working with real fluid **Real Gas** must be selected and **From NIST** button should be pressed to open the mixture options window.

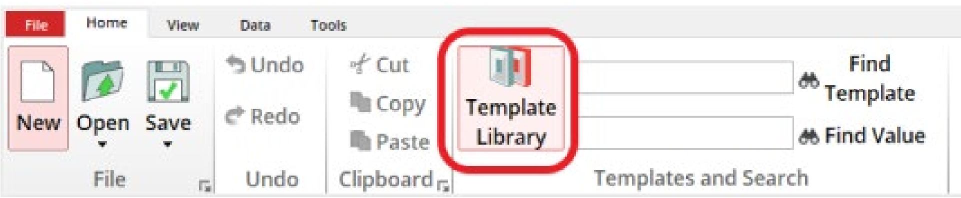


The appropriate mixture should be specified. Mixture name is a crucial element in this step. This is the parameter passed to the GT-SUITE model when running the simulation. It should be expressed exactly as it appears in the GT-SUITE Template Library and it is case sensitive.

At least two components of the mixture must be selected for this feature to work properly. Amount of each component is not a major property as only the name of the mixture is used in this case.

Also, some of the pure fluids are named differently in GT-SUITE and SCORG. For example, in SCORG R134a appears as **R134A** and in GT-SUITE as **R134a**. In SCORG mixture window select *R134A* fluid, add another component which amount can be set to 0 and name the mixture as ***R134a*** then press **Save** button.

All the available fluids to be chosen in GT-SUITE are listed in the GT-SUITE Template Library under **Flow/References/Fluid…**



- Working Conditions

Working Conditions		
Wtip	80	m/s
Rotor Speed	12000	RPM
P0	1	bar
Pr	3	bar
T0	293	K
Tr	350	K
Tevp	268	K
Tcond	313	K
T Ambient	293	K
Include heat transfer	No	
X	1	

The rotational speed can be defined by the tip speed or by the Rotor speed. Whichever value is set, the other will automatically adjust according to the size of the rotor.

The values required to be set for this calculation are

P0 – Suction pressure (absolute)

T0 – Suction Temperature

Pr – Discharge Pressure.

Tr – discharge Pressure

- Liquid injection

Fluid Injection		
Fluid Injection	Off	
P	3	bar
T	310	K
Injection Angle	63.025	Deg
Axial Position	0.1	m
Port Diameter	0.005	m
Doil	1E-05	m
CpOil	2000	J/(kg.K)
ρ	845	kg/m³
Viscosity of Oil	5E-05	m²/s

For oil-free screw compressor, the Fluid Injection control button should be off. In such a case, it is irrelevant what the other values are in this input window as these are not used in the calculation.

- Additional Injection Port

Additional Injection Port		
Additional Port	No	
P	3	bar
T	310	K
Fluid Quality	Liquid	
Injection Angle	63.025	Deg
Axial Position	0.1	m
Port Diameter	0.02	m

Similarly, for the Additional Port, it should be off.

- Bearings and seals

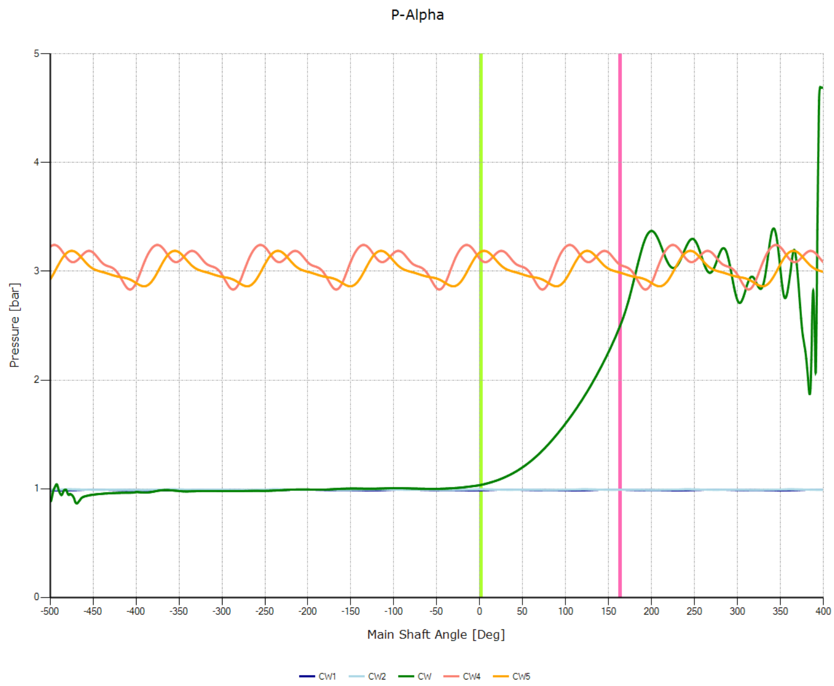
Bearings and seals		
Bearing Type	Rolling El...	
N Shaft	4	
Seal Ploss	300	W/1000R...
Diameter Factor	0.02285	
Speed Factor	0.000835	

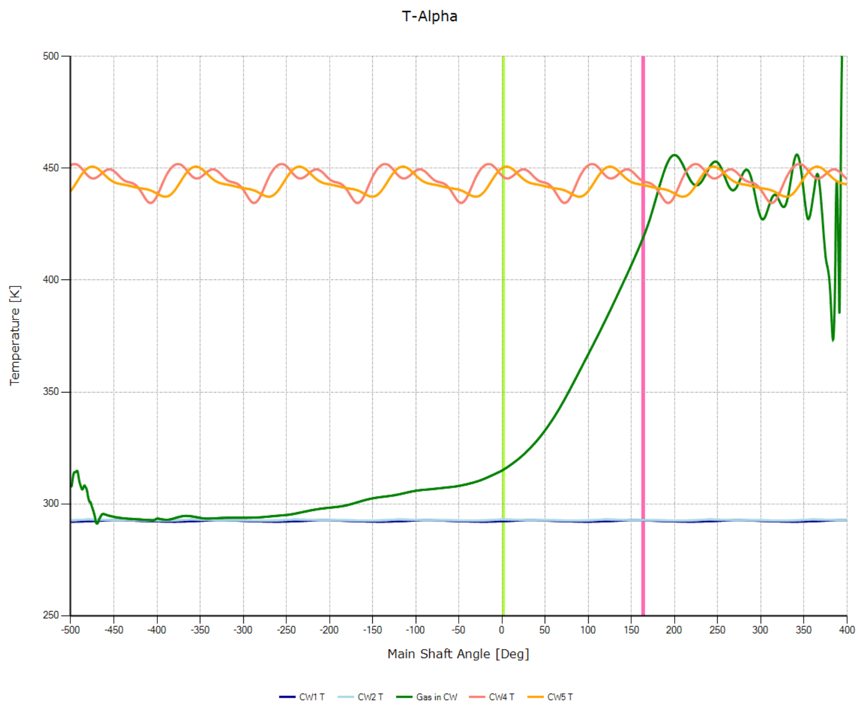
Depending on the "Bearing Type" setting, one of either the RollerBearingsAssy or JournalBearingsAssy subassemblies will be chosen for use in the GT main model. If no bearings are desired, all of the 4 input parameters below "Bearing Type" can be set to 0. This will automatically select the NoBearingsAssy within the main GT model. For this exercise, set the 4 inputs to 0 and run SCORG Thermodynamics prior to Force calculations to generate the Forces_R1_GT.txt and Forces_R2_GT.txt files.

4.3 Oil-free compressor calculation

- Calculate Thermodynamics by selecting Thermodynamics Calculations shortcut.

- Inspect the thermodynamic diagrams.





The above two diagrams show Pressure change with the angle of rotation and the temperature change with the angle of rotation respectively. The green line marked with CW represents the main working chamber.

The blue (CW1) and green (CW2) lines are low pressure pipe and reservoir respectively.

The red (CW4) and orange (CW5) lines are high pressure reservoir and pipe respectively.

The pulsations in the main chamber and in the pipes and reservoirs are visible on the above charts.The Mass-Alpha diagram is currently not available for this calculation. However, further results can be obtained using GT-POST application. This will be discussed later.

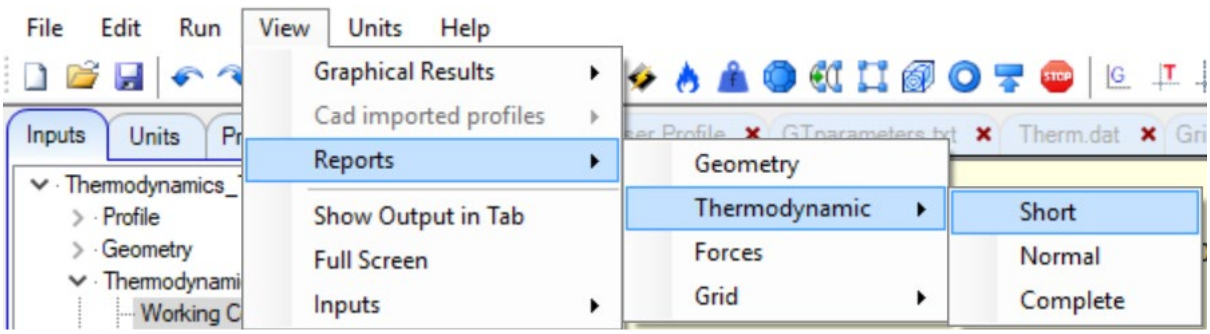
- Results presented on the screen after the calculations are finished show calculated integral parameters and Case Setup. Some values like temperature and pressure of the oil are printed even when fluid is not injected.

```
| CASE #  1
|Tinl              Pinl          Moil          Tout          Pout          Toil          Poil          Volume Index Vi Speed
Theoretical Mas
|C                 bar           kg/s          C             bar           C             bar           No Unit         RPM
kg/h
  19.627826        0.99160801    0.0000000     171.80996     3.0757345     36.850000     3.0000000     1.8000000       12000.040
1466.0172
```

```
Tip Speed    Vol. Flow Rate  Vol. Flow Rate  Mass Flow Rate  Vol. Efficiency  Fluid Power  Fluid Power
m/s          m^3/min         m^3/h           kg/h            %                kW           HP
 80.000130    16.414800       984.91571       1162.7250       80.042254        50.043029    67.108794
```

- View Thermodynamic Report

While using GT-SUITE solver, the same results as above can be viewed as a short report.




```
|| CASE #  1
|Tinl          Pinl          Moil          Tout          Pout          Toil          Poil          Volume Index Vi  Speed
|C             bar           kg/s          C             bar           C             bar           No Unit          RPM
  19.627826    0.99160801    0.0000000     171.80996     3.0757345     36.850000     3.0000000     1.8000000        12000.040
```

Tip Speed m/s	Vol. Flow Rate m^3/min	Vol. Flow Rate m^3/h	Mass Flow Rate kg/h	Vol. Efficiency %	Fluid Power kW	Fluid Power HP
80.000130	16.414800	984.91571	1162.7250	80.042254	50.043029	67.108794

4.4 Changing compressor geometry and operating parameters

The thermodynamic module allows variation of parameters and evaluation of their influence on the performance of the compressor. As an example, the following changes will be introduced:

- Radial clearance will be changed to 50 micrometres,
- Volume Index will be increased to 2.2
- Discharge pressure will be reduced to 2.5 bar
- Size of the discharge pipe (flange) will be changed to 70 mm

To introduce these changes please alter windows below:

Profile

Profile Setup		
Profile Choice	User Spe...	
Axis Distance	0.093	m
Z1	3	
Z2	5	
GAPI	0.00018	m
GAPR	0.00005	m
GAPA	0.0001	m

Geometry

Machine Configuration		
Machine Type	Screw C...	
N Gate	1	
Compression Start	0	Deg
Compression End	189.49	Deg
Volume Index	2.2	
Angle of Radial Discharge...	0	Deg
E Rotor	211	GPa
αL Rotor	1E-05	m/m/K
E Casing	211	GPa
αL Casing	1E-05	m/m/K
Wall Roughness	0	m

Thermodynamics

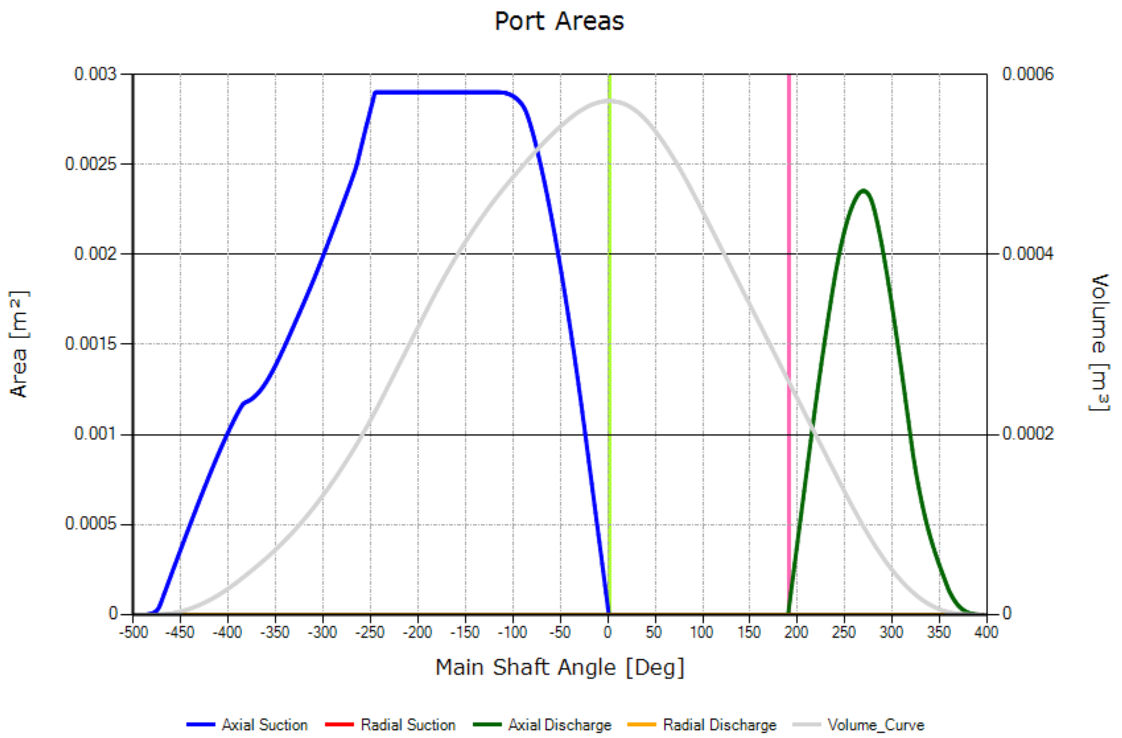
Working Conditions		
Wtip	80	m/s
Rotor Speed	12000	RPM
P0	1	bar
Pr	2.5	bar
T0	293	K
Tr	350	K
Tevp	268	K
Tcond	313	K
T Ambient	293	K
Include heat transfer	No	
X	1	

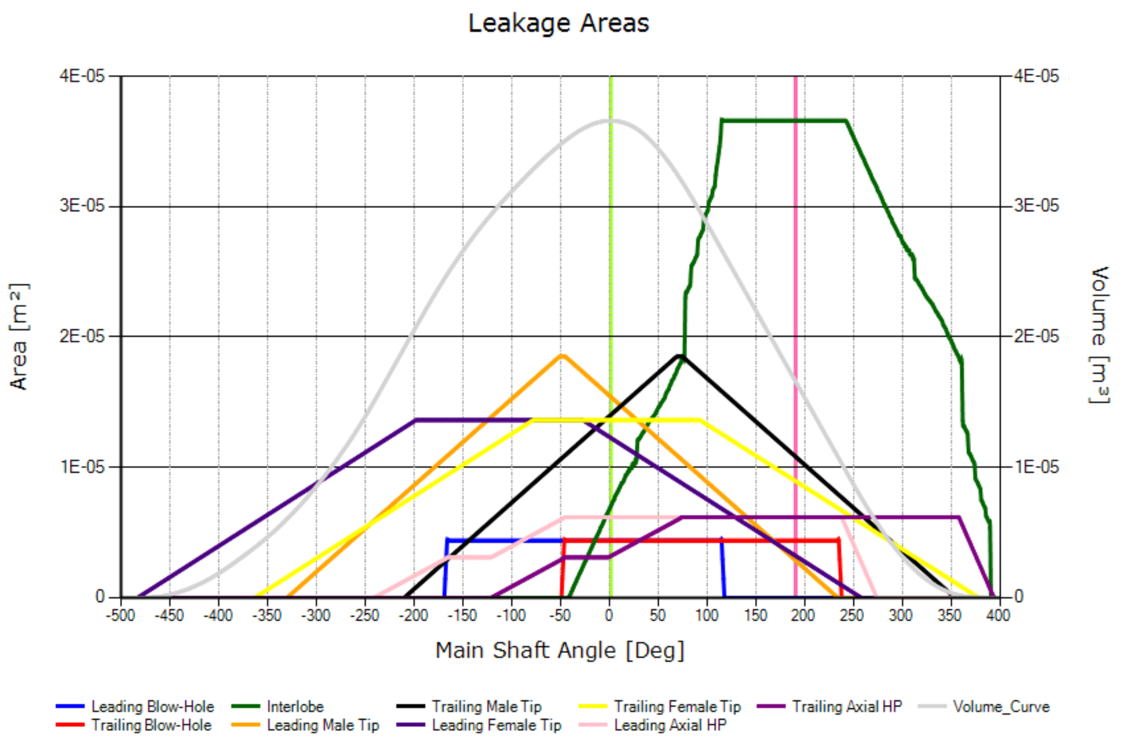
Domains

High Pressure Pipe		
Diameter	0.07	m
Length	0.2	m

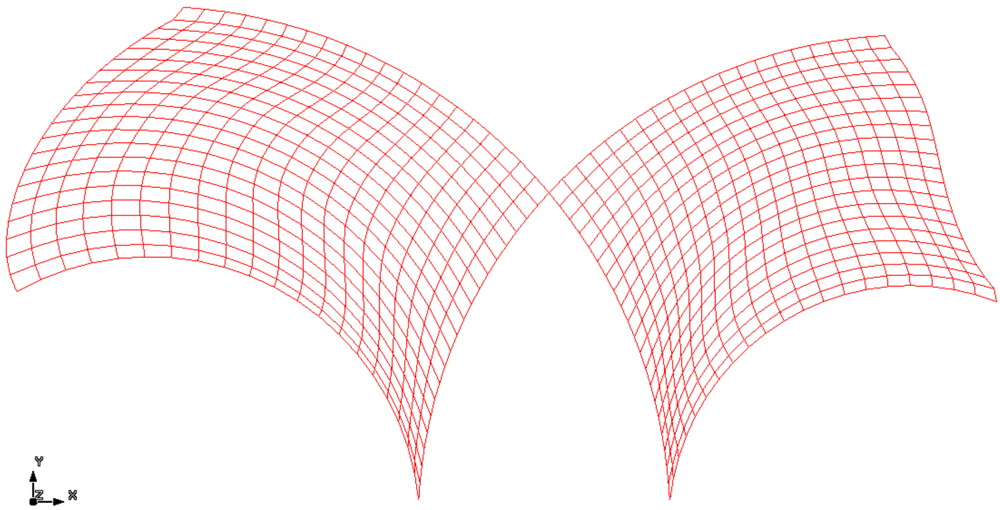
- Run Geometry calculation; Run Port Generation and Run Thermodynamics.
- Inspect the results and compare with the results obtained previously.

a) Geometry Diagrams - Note the difference in the size of the discharge port, Compression angle and the size of radial gaps.

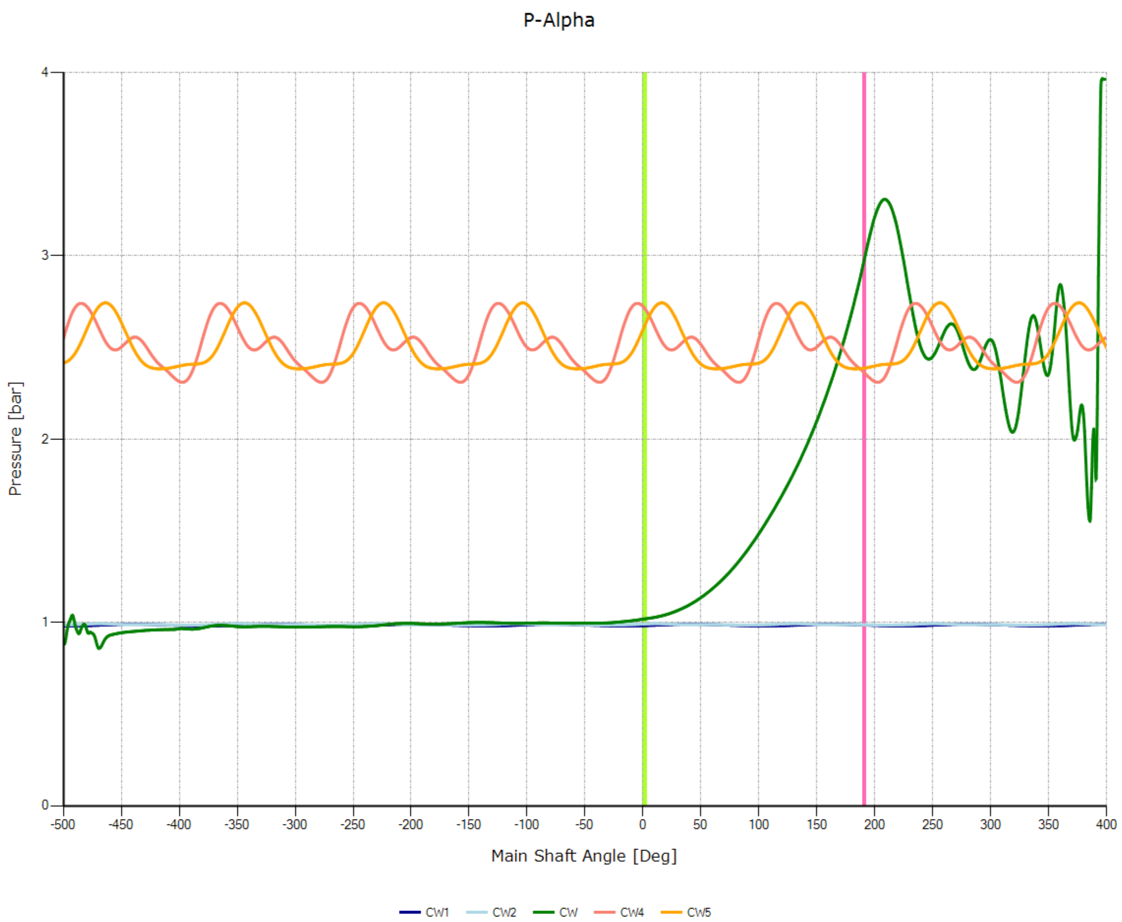




b) Note the difference in the size and shape of the discharge port.



c) Note the difference in the thermodynamic performance. The compressor now over compresses but the larger flow area behind the compressor introduces lower losses in the discharge reservoir and pipes and therefore lower pressure.

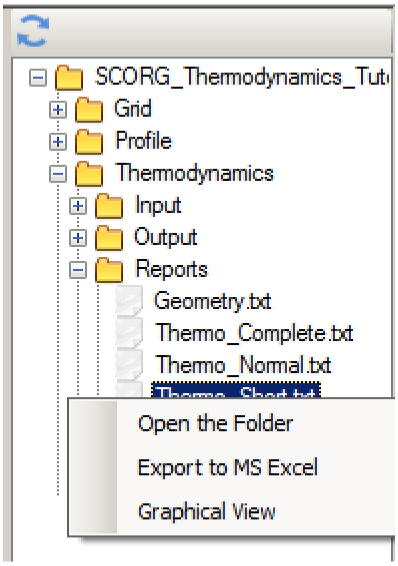


d) Inspect Thermodynamic report.

CASE # 1								
Tinl	Pinl	Moil	Tout	Pout	Toil	Poil	Volume Index Vi	Speed
C	bar	kg/s	C	bar	C	bar	No Unit	RPM
19.541446	0.99019483	0.0000000	133.45414	2.5122368	36.850000	3.0000000	2.2000000	12000.040

Tip Speed	Vol. Flow Rate	Vol. Flow Rate	Mass Flow Rate	Vol. Efficiency	Fluid Power	Fluid Power	Theoretical Mas
m/s	m^3/min	m^3/h	kg/h	%	kW	HP	kg/h
80.000130	17.842553	1070.5833	1262.0453	86.975206	40.989092	54.967268	1466.0172

Once the results are calculated, these can be viewed in the report as presented before or exported to excel where these could be used for preparing diagrams etc. To export in excel select the Thermo_Short.txt report from the Case tree, click on the right mouse button and select 'Export to excel' as shown in the figure



The results will be in the form shown below.

| CASE # 1																
|Tinl	Pinl	Moil	Tout	Pout	Toil	Poil	Volume Index Vi Speed	Tip Speed	Vol. Flow Rate	Vol. Flow Rate	Mass Flow Rate	Vol. Efficiency Fluid Power	Fluid Power	Theoretical Mas		
|C	bar	kg/s	C	bar	C	bar	No Unit	RPM	m/s	m^3/min	m^3/h	kg/h	%	kW	HP	kg/h
19.541446	0.99019483	0.0000000	133.45414	2.5122368	36.850000	3.0000000	2.2000000	12000.040	80.000130	17.842553	1070.5833	1262.0453	86.975206	40.989092	54.967268	1466.0172

4.5 Calculating Oil injected case

Majority of screw compressors today are oil injected. Oil is injected to seal, cool and lubricate the rotors. Rotors are in direct contact. Oil injected compressors achieve higher pressure ratios and lower discharge temperatures, rotate at lower speeds than oil-free compressors and allow clearances to be much lower than in oil-free machines.

The same compressor will be used for oil injection calculation.

The profile will be set with a nominal clearance of 50 micrometres, Volume Index will be set to 5, tip speed to 40 m/s, discharge pressure to 8 bar. Oil injection will be switched on, Oil injection pressure set to 7 bar through oil injection port positioned at 60 degrees of the rotation of the male rotor from the closing of the suction port and oil will be injected at 310 K.

Please set the values as indicated in the figure below.

Profile

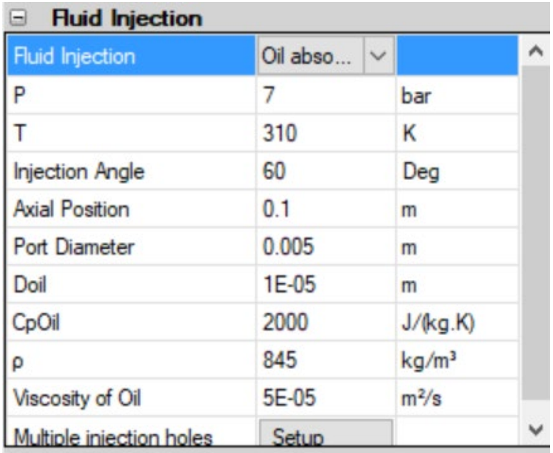
Profile Setup		
Profile Choice	User Spe...	
Axis Distance	0.093	m
Z1	3	
Z2	5	
GAPI	0.00018	m
GAPR	5E-05	m
GAPA	5E-05	m

Geometry

Machine Configuration		
Machine Type	Screw C...	
N Gate	1	
Compression Start	0	Deg
Compression End	259.899	Deg
Volume Index	5	
Angle of Radial Discharge...	0	Deg
E Rotor	211	GPa
αL Rotor	1E-05	m/m/K
E Casing	211	GPa
αL Casing	1E-05	m/m/K
Wall Roughness	0	m

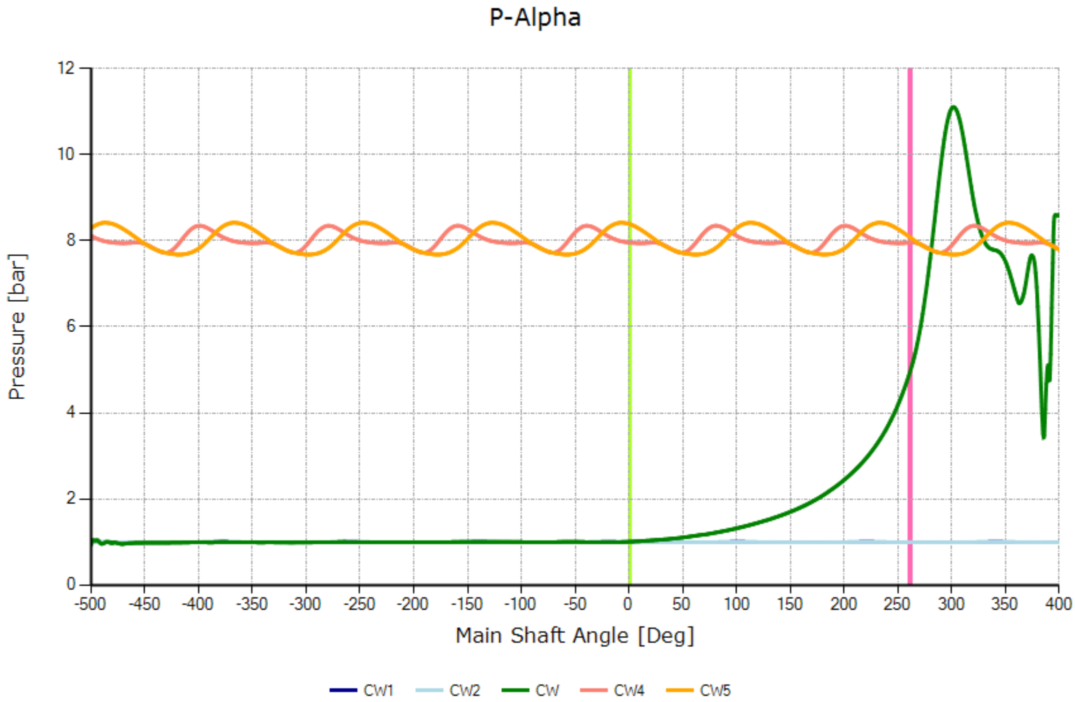
Thermodynamics

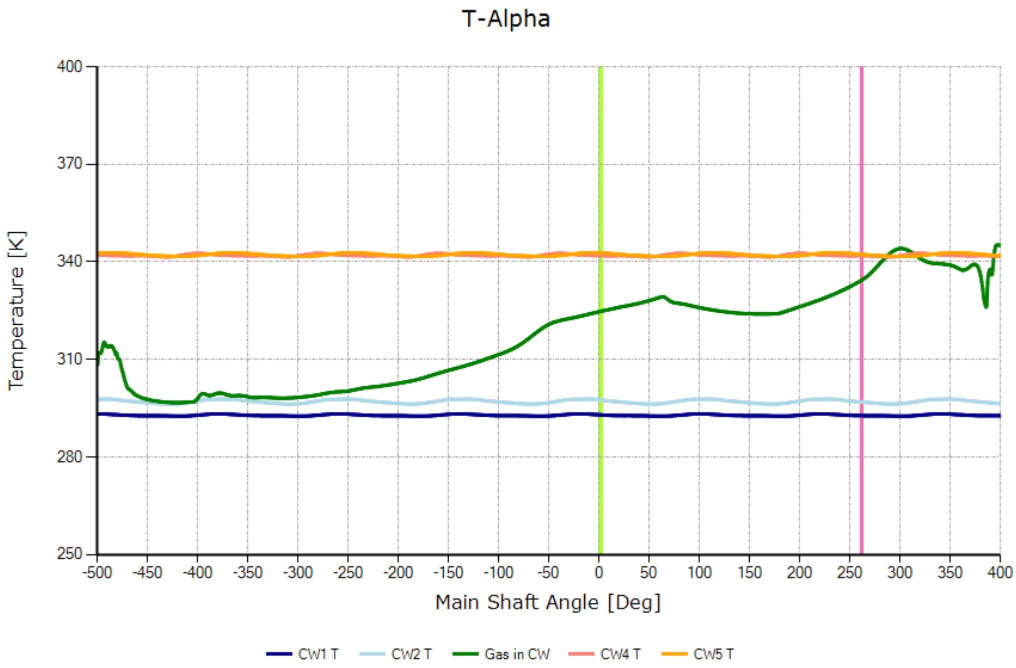
Working Conditions		
Wtip	40	m/s
Rotor Speed	6000	RPM
P0	1	bar
Pr	8	bar
T0	293	K
Tr	350	K
Tevp	268	K
Tcond	313	K
T Ambient	293	K
Include heat transfer	No	
X	1	



Fluid Injection		
Fluid Injection	Oil abso...	
P	7	bar
T	310	K
Injection Angle	60	Deg
Axial Position	0.1	m
Port Diameter	0.005	m
Doil	1E-05	m
CpOil	2000	J/(kg.K)
ρ	845	kg/m³
Viscosity of Oil	5E-05	m²/s
Multiple injection holes	Setup	

- Calculate Thermodynamics.
- View diagrams.





Notice the red line which represents the oil in the working chamber. As currently, heat transfer is assumed to be instantaneous, the temperature of the gas and oil are the same line. Oil is injected at 60 deg and is used to cool the air. Despite the discharge pressure reaching almost 9 bar, the discharge temperature is around 80 deg C.

The results displayed in the results window:

CASE # 1

Tinl	Pinl	Moil	Tout	Pout	Toil	Poil	Volume Index Vi	Speed
C	bar	kg/s	C	bar	C	bar	No Unit	RPM
19.778183	0.99759055	0.50603630	72.845085	8.1570039	40.003733	6.4254491	5.0000000	6000.0200

Tip Speed	Vol. Flow Rate	Vol. Flow Rate	Mass Flow Rate	Vol. Efficiency	Fluid Power	Fluid Power	Theoretical Mas
m/s	m^3/min	m^3/h	kg/h	%	kW	HP	kg/h
40.000060	8.7796663	526.79479	625.38711	85.505744	42.554207	57.066121	733.00861

The Report

CASE # 1

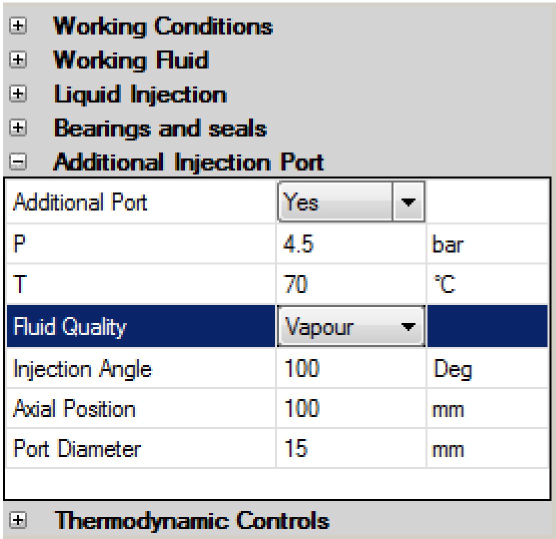
Tinl	Pinl	Moil	Tout	Pout	Toil	Poil	Volume Index Vi	Speed
C	bar	kg/s	C	bar	C	bar	No Unit	RPM
19.778183	0.99759055	0.50603630	72.845085	8.1570039	40.003733	6.4254491	5.0000000	6000.0200

Tip Speed	Vol. Flow Rate	Vol. Flow Rate	Mass Flow Rate	Vol. Efficiency	Fluid Power	Fluid Power	Theoretical Mas
m/s	m^3/min	m^3/h	kg/h	%	kW	HP	kg/h
40.000060	8.7796663	526.79479	625.38711	85.505744	42.554207	57.066121	733.00861

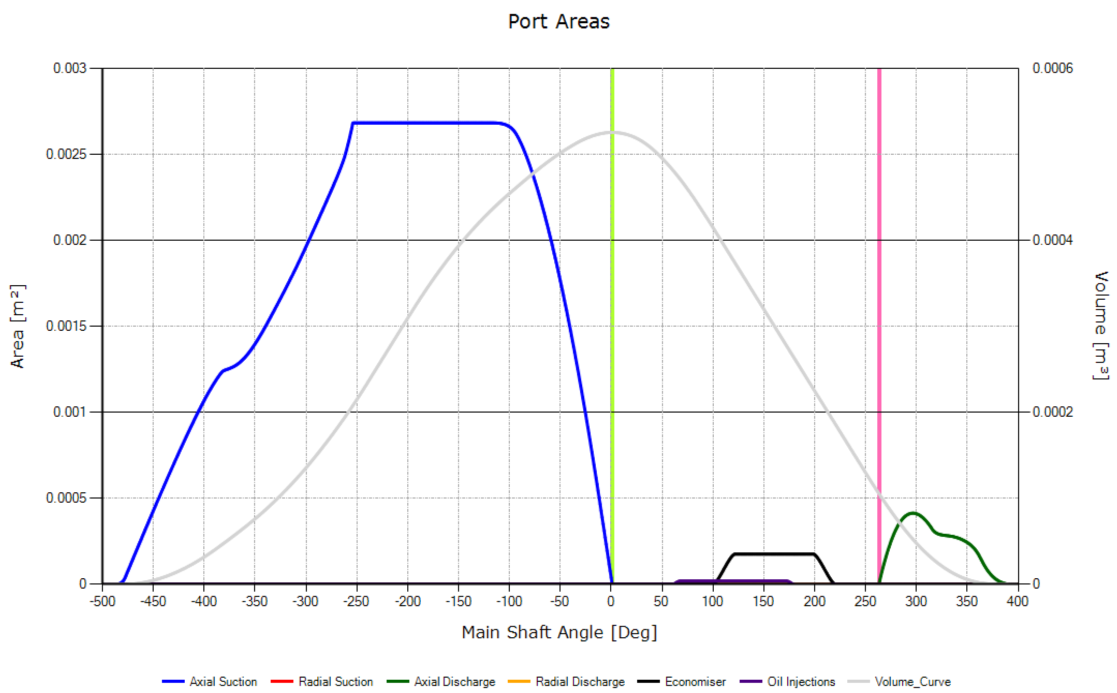
An increase in the mass in the working chamber can be observed.

- Additional port

Often, oil injected screw compressors have an additional injection port, which in refrigeration is referred to as the economizer port. In SCORG, the additional injection port is enabled through Thermodynamics->Additional Injection Port tab:

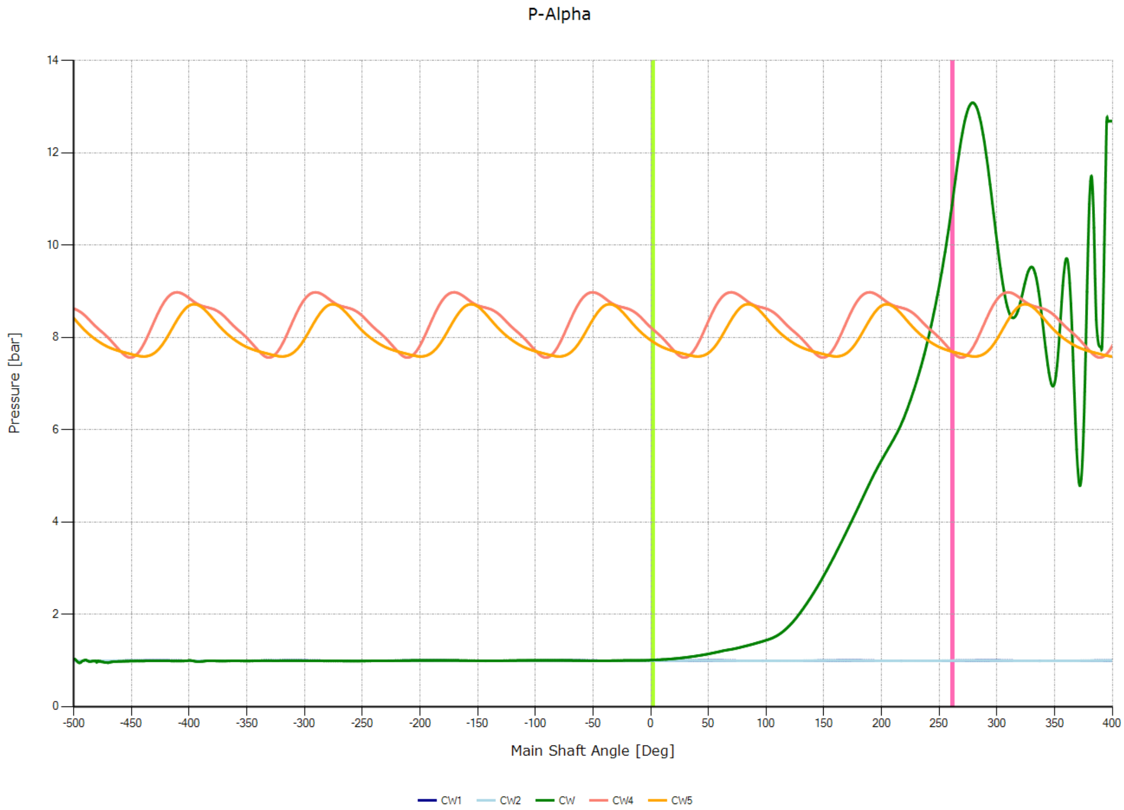


It is necessary to specify the position and size of the additional port as well as the pressure and temperature in the port. Before thermodynamics can be calculated, it is important to calculate geometry. The additional injection port is shown as an economiser in the figure below



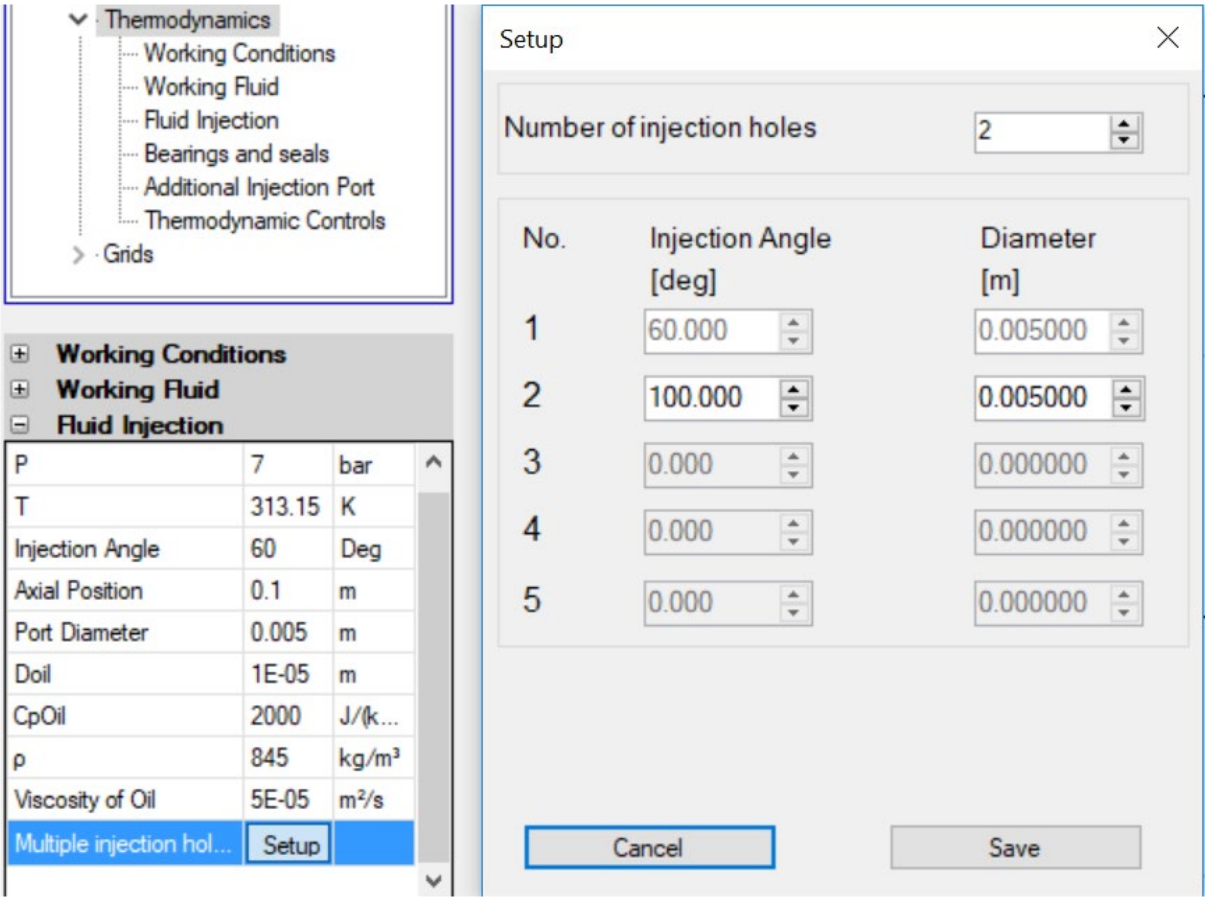
Once thermodynamics is calculated, it is possible to observe results through the thermodynamic diagrams below.

Notice the change in the pressure diagram where a sudden increase in the pressure can be observed from the angle of 100 deg.



The additional injection port can be also used for the injection of additional liquid in the working domain. However, calculations using GT-SUITE are currently limited to be the same as the working fluid, in this case the refrigerant.

In oil-injected compressors, the liquid injected is oil. To enable additional oil injection, it can be set up in Fluid Injection, under Multiple injection holes.



The same liquid selected in the Fluid Injection input will be injected through both injection holes. In this case, it is oil.

The results of thermodynamics calculation without the additional oil injection are shown below (Economizer port is off).

CASE # 1

Tinl	Pinl	Moil	Tout	Pout	Toil	Poil	Volume Index Vi	Speed
C	bar	kg/s	C	bar	C	bar	No Unit	RPM
19.778183	0.99759055	0.50603630	72.845085	8.1570039	40.003733	6.4254491	5.0000000	6000.0200

Tip Speed	Vol. Flow Rate	Vol. Flow Rate	Mass Flow Rate	Vol. Efficiency	Fluid Power	Fluid Power	Theoretical Mas
m/s	m^3/min	m^3/h	kg/h	%	kW	HP	kg/h
40.000060	8.7796663	526.79479	625.38711	85.505744	42.554207	57.066121	733.00861

Once the additional oil injection is enabled, the overall mass flow rate and the performance will change dramatically:

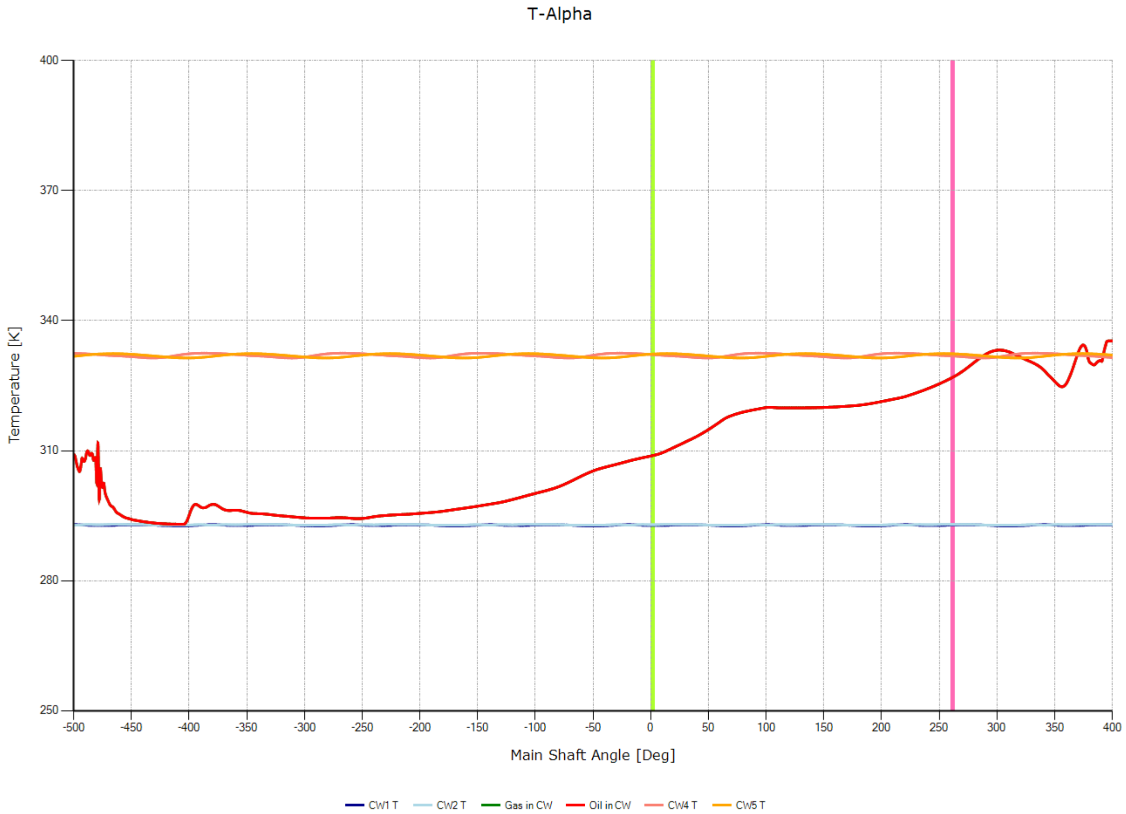
CASE # 1

Tinl	Pinl	Moil	Tout	Pout	Toil	Poil	Volume Index Vi	Speed
C	bar	kg/s	C	bar	C	bar	No Unit	RPM
19.768854	0.99750321	0.96739468	58.837629	8.2564102	40.017508	5.5061107	5.0000000	6000.0200

Tip Speed	Vol. Flow Rate	Vol. Flow Rate	Mass Flow Rate	Vol. Efficiency	Fluid Power	Fluid Power	Theoretical Mas
m/s	m^3/min	m^3/h	kg/h	%	kW	HP	kg/h
40.000060	8.9551117	537.32181	637.82665	87.261066	43.532245	58.377691	733.00861

Almost double the amount of oil is injected which results in increased drag losses due to oil in the chamber leading to an overall slightly higher power.

The discharge temperature also changed as shown in the figure below.



4.6 Expander calculation

GT-SUITE allows also for the simulation of an expander. Used Inputs are set to the original values as presented in section 1 and 2. With the difference in Machine configuration. Machine Type is now set to be Screw Expander.

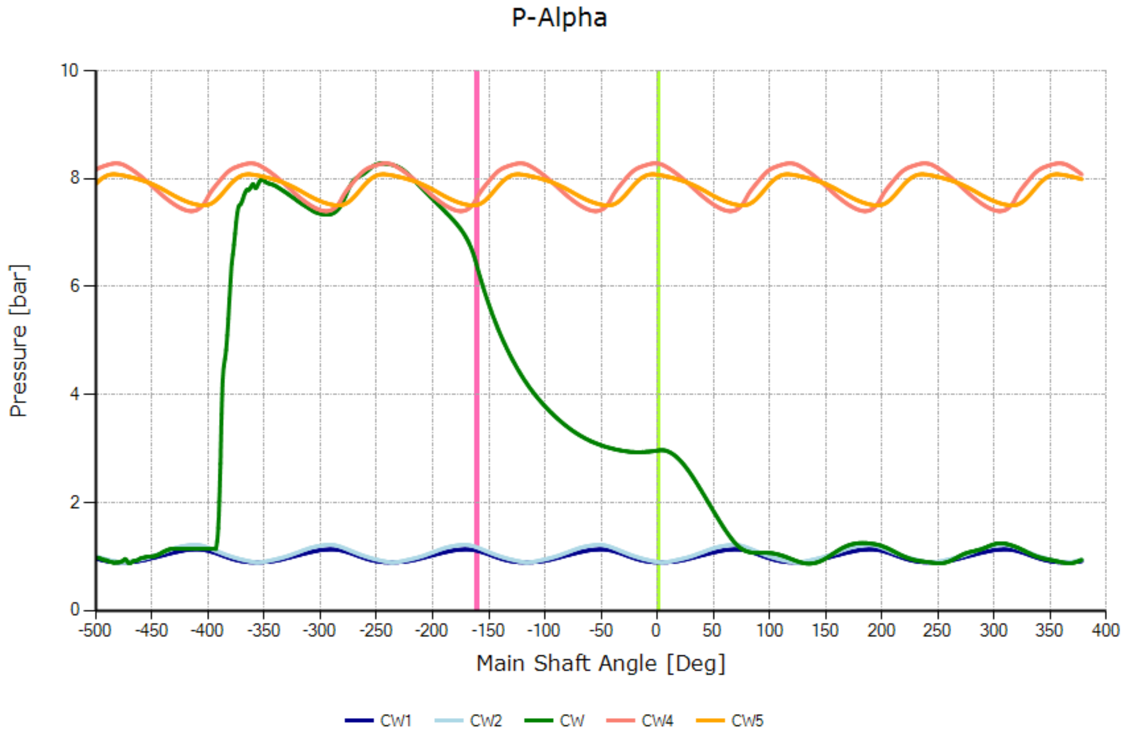
Machine Configuration		
Machine Type	Screw Expa	
N Gate	1	
Compression Start	0	Deg
Compression End	161.792	Deg
Volume Index	1.8	
Angle of Radial Discharge...	0	Deg
E Rotor	211	GPa
αL Rotor	1E-05	m/m/K
E Casing	211	GPa
αL Casing	1E-05	m/m/K
Wall Roughness	0	m

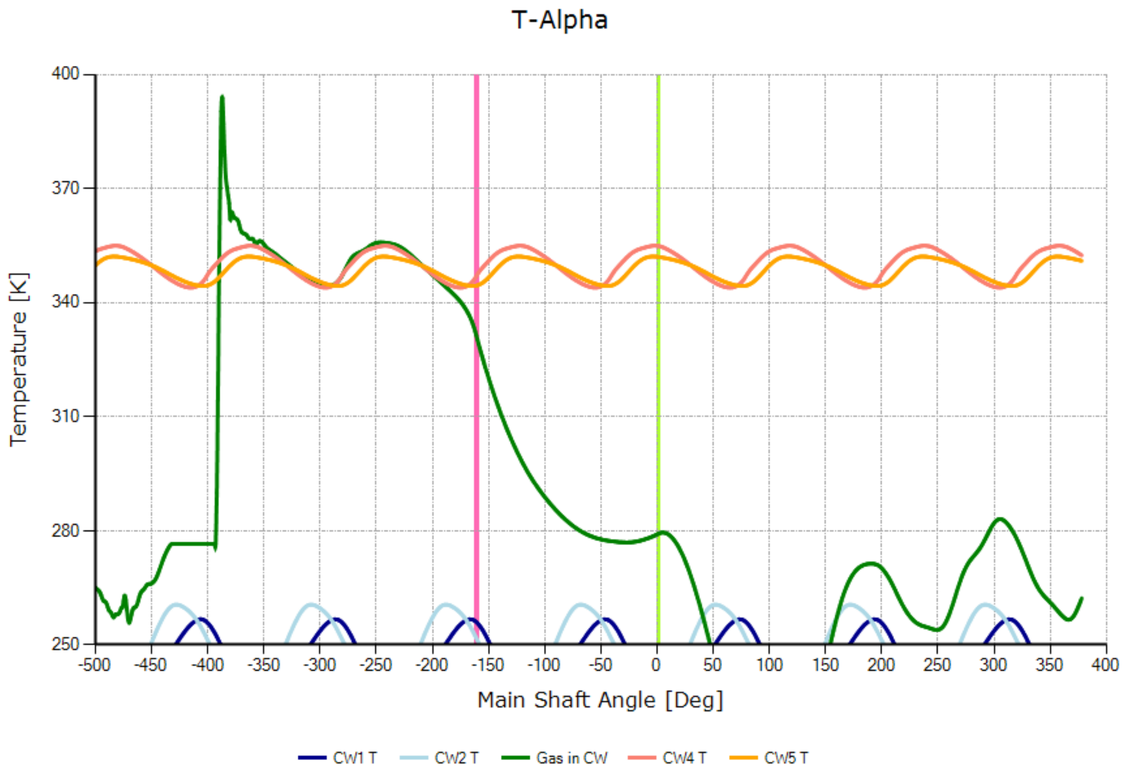
Thermodynamics inputs are set to previous values from section 4.3 with fluid injection switched off.

Fluid Injection		
Fluid Injection	Off	
P	3	bar
T	310	K
Injection Angle	63.025	Deg
Axial Position	0.1	m
Port Diameter	0.005	m
Doil	1E-05	m
CpOil	2000	J/(kg.K)
ρ	845	kg/m³
Viscosity of Oil	5E-05	m²/s

- Calculate Geometry and Thermodynamics

- Inspect thermodynamics diagrams. Note that results for the expander are written and shown in reverse. This means the cycle starts on the right-hand side and ends at the left-hand side of the diagram.


P-Alpha
Pressure [bar]
Main Shaft Angle [Deg]
CW1
CW2
CW
CW4
CW5


T-Alpha
Temperature [K]
Main Shaft Angle [Deg]
CW1 T
CW2 T
Gas in CW
CW4 T
CW5 T

- View the report

CASE # 1

Tinl	Pinl	Moil	Tout	Pout	Toil	Poil	Volume Index Vi	Speed
C	bar	kg/s	C	bar	C	bar	No Unit	RPM
-25.409566	1.0523734	-3.54849853E-14	76.739786	7.8727925	36.850000	7.0000000	1.8000000	6000.0200

Tip Speed	Vol. Flow Rate	Vol. Flow Rate	Mass Flow Rate	Vol. Efficiency	Fluid Power	Fluid Power	Theoretical Mas
m/s	m^3/min	m^3/h	kg/h	%	kW	HP	kg/h
40.000060	-35.737080	-2144.2851	-3050.0682	323.46447	-84.485464	-113.29685	733.00861

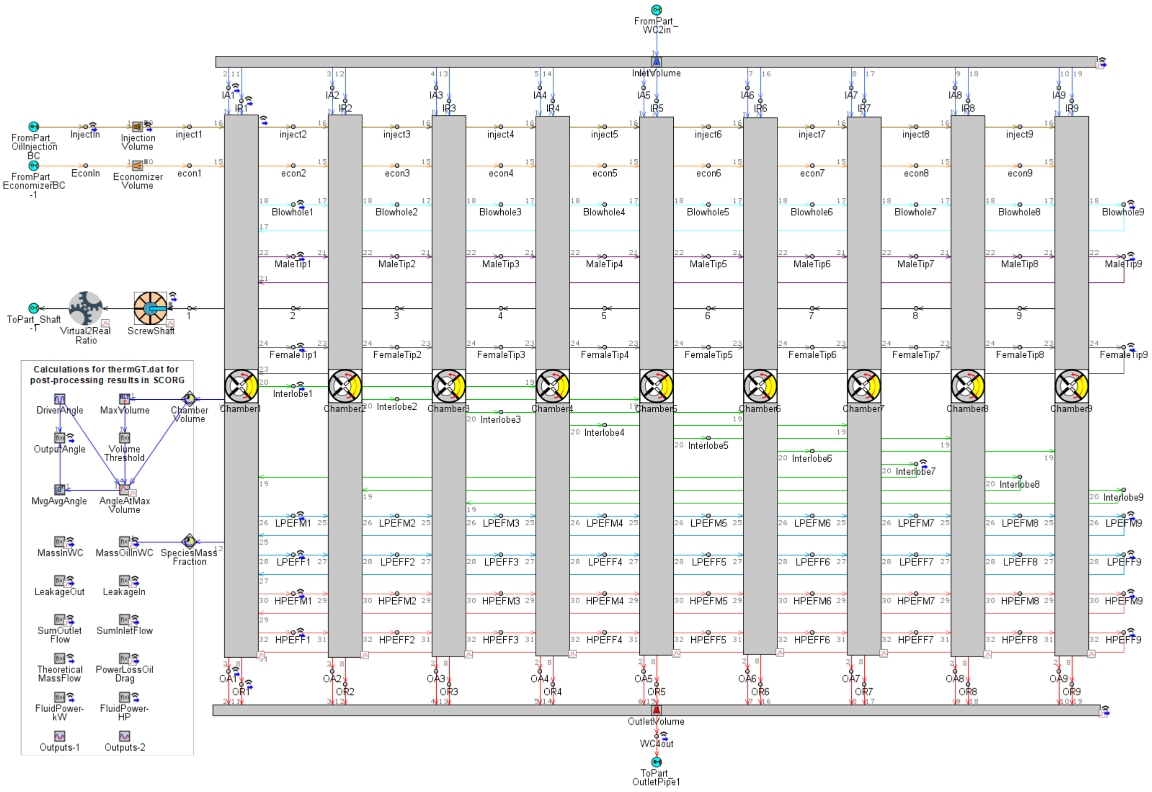
More detailed results can be seen within the GT-POST application, which is discussed in section 4.8.

4.7 GT-SUITE model overview

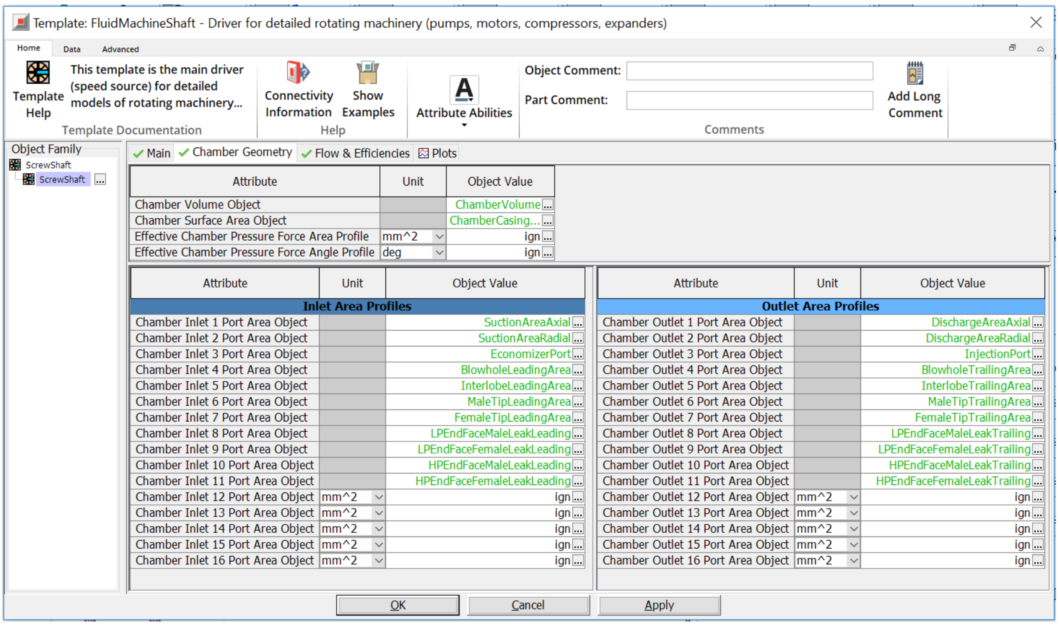
As discussed before, to carry out the calculations with the integrated GT-SUITE solver, the GT template model (.gtm), the bearings subassembly model (.gtsub) and four additional files are used (GeomGT.txt, GTparameters.txt, Forces_R1_GT.txt and Forces_R2_GT.txt).

Setup of the model is based on the geometry and parameters obtained through the calculations within SCORG. It is possible to further adjust the parameters to meet the user's requirements. For example, simulating oil injected refrigeration screw compressor may currently have some limitations which can be solved through user's modifications. This is further explained in the SCORG User Manual Section 8.10.3.

ScrewMachineChambers part needs to be considered in case of any changes. It differs between the templates depending on the number of chambers.

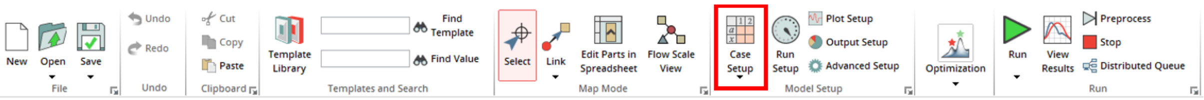


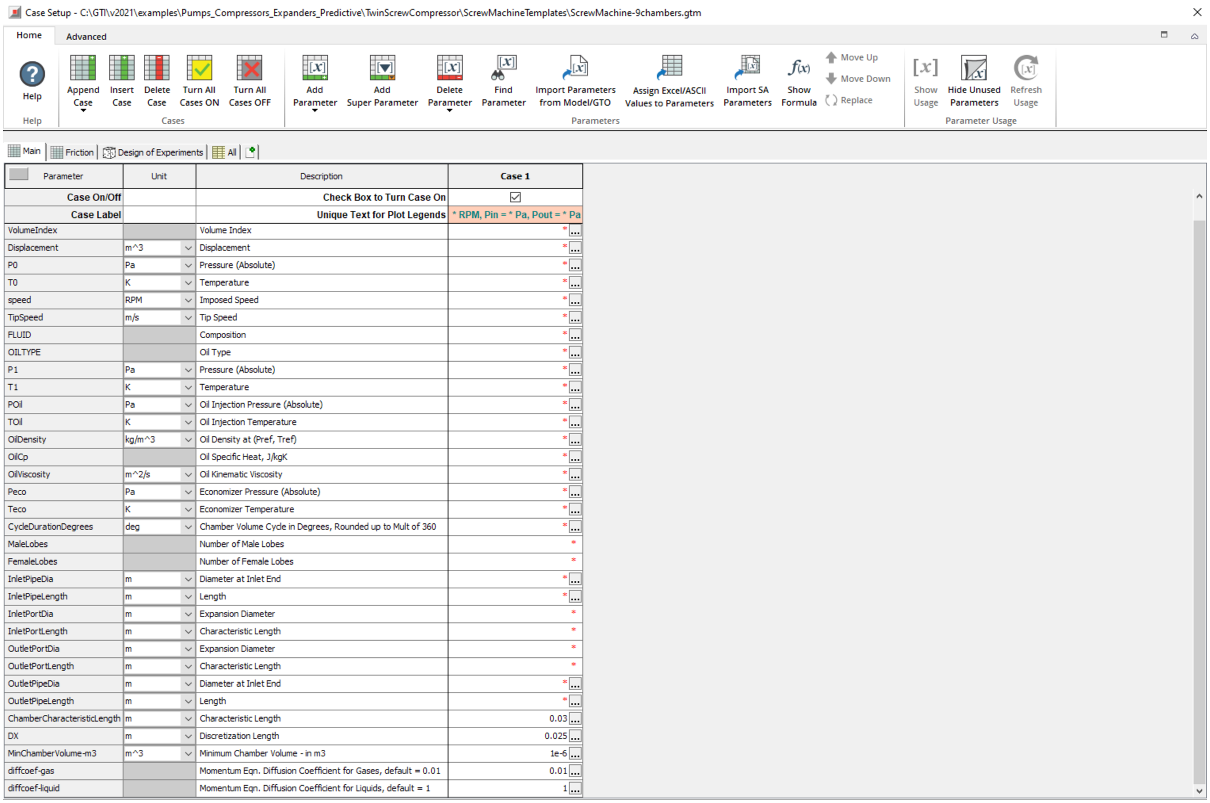
Links between the chambers and inlet and outlet volumes represent flows. The area of the flow depends on the current angular position of the shaft. This is based on the geometry obtained in SCORG and driven by the **ScrewShaft** part. Double-clicking it will open the following window in which all of the chamber geometry profiles are referenced.



All the area profile objects are imported from the GeomGT.txt file. Modification of this **ScrewShaft** part is not advised.

Parameters setting the conditions under which simulation is run are imported directly from the GTparameters.txt. file and can be seen under **Case Setup**.

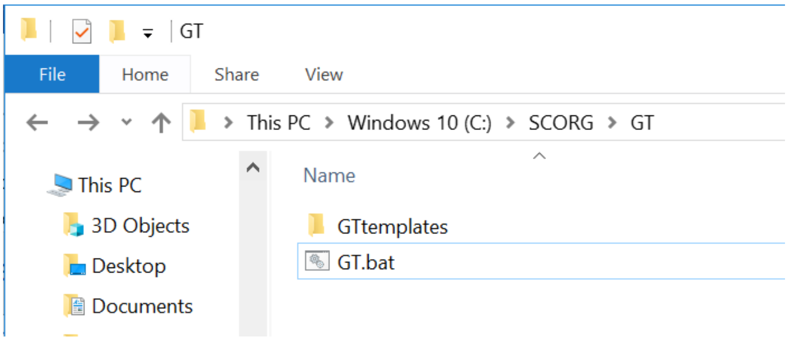




The red * indicates that the value is linked to the corresponding parameter in the file. It may be required to change some of the values to the user's intended values. For example, FLUID in oil injected refrigeration screw compressor must be customized by the user. Case Setup can also be used to set up cases with different working conditions. The Append Case or Insert Case buttons can be used to add additional cases.

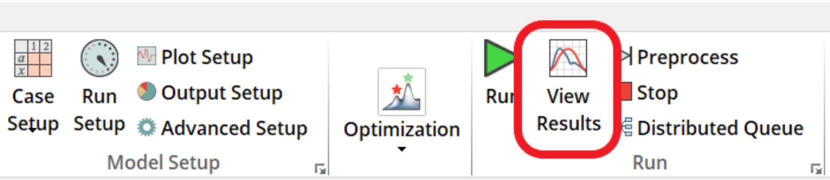
For additional user control over the amplitude and frequency of the pressure pulsations within the chambers of the screw machine, the two parameters – [diffcoef-gas] and [diffcoef-liquid] – can be varied to study the effect of damping the diffusion coefficient term in the momentum equation solved by GT-SUITE. By default, their values are 0.01 and 1 respectively but the gas diffusion coefficient multiplier can be varied anywhere from 1 to 10 depending on the size of the compressor. Please contact GT Support (support@gtisoft.com) for further information regarding these parameters.

For the ease of multiple calculations with different setups, a batch file may be run, altering values in the GTparameters.txt file.



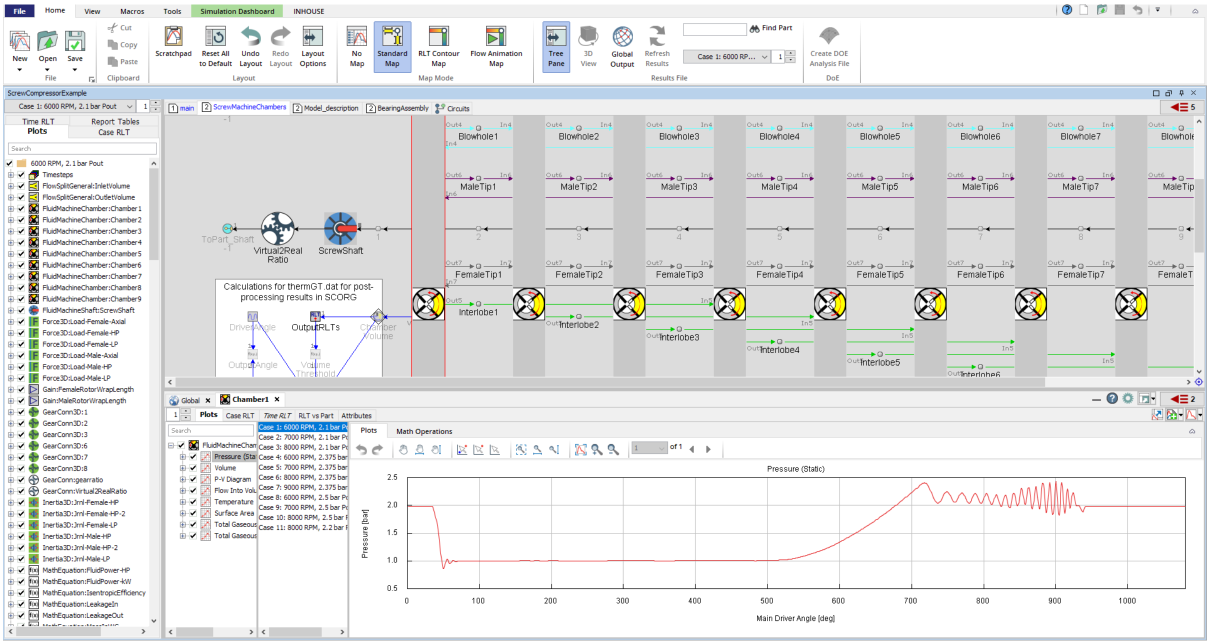
4.8 Further results

More detailed results of the simulations can be accessed through GT-SUITE application. After the calculation was successfully carried out, clicking the **View Results** button while the model template is open or opening *.gdx file (C:\SCORG\GT\) will run GT-POST application.



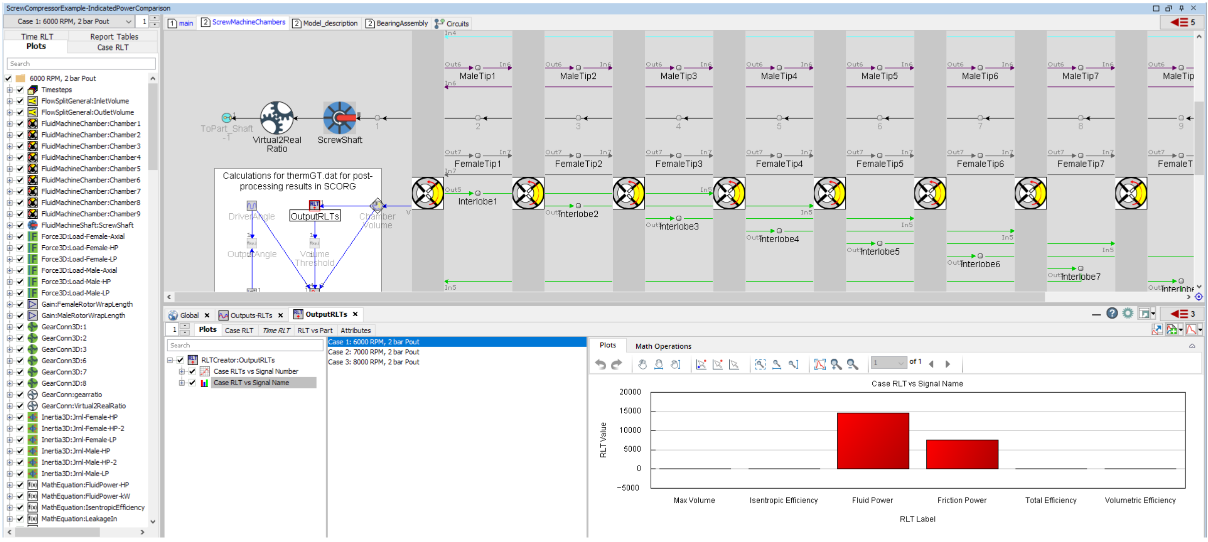
This allows seeing results at specific parts of the machine. Especially data under **FluidMachineShaft:ScrewShaft** may be of the main interest.

Clicking on one of the FluidMachineChamber parts (Chamber 1) will show the different instantaneously varying quantities such as pressure, temperature, etc. within the screw machine chamber. Shown below is the instantaneous pressure within the chamber.

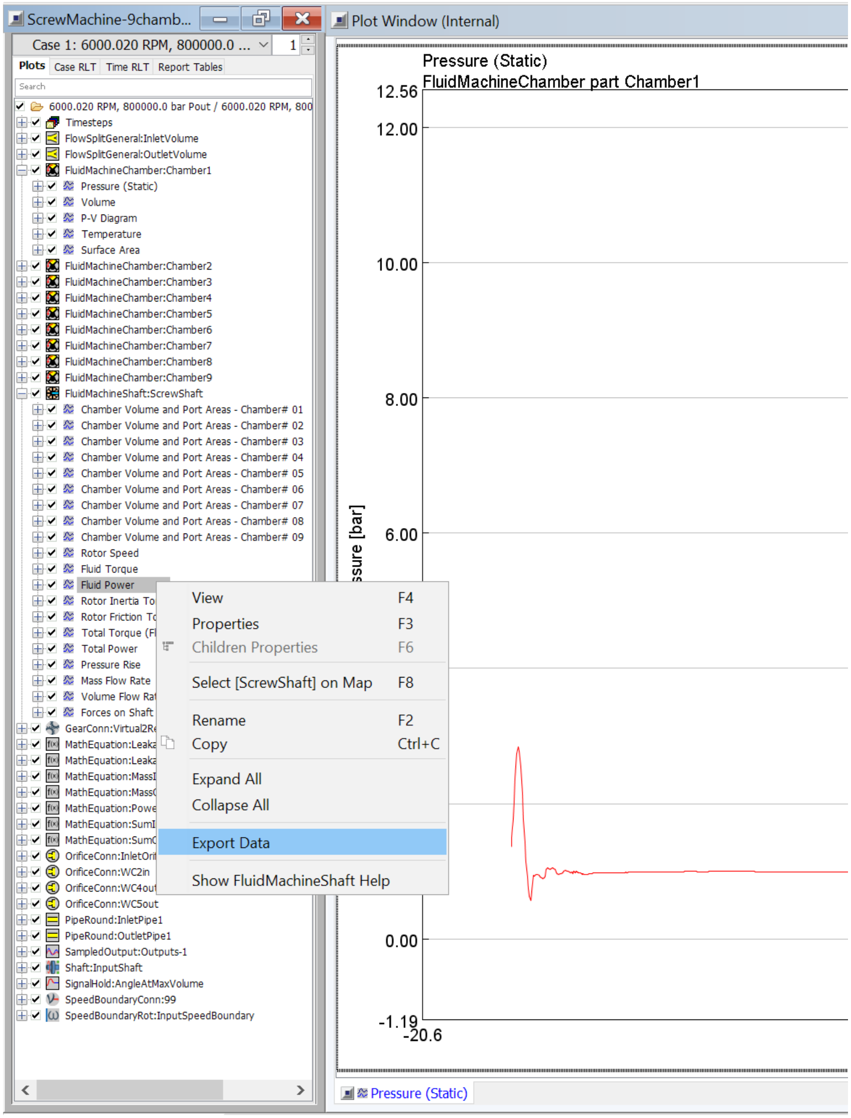


The plot is drawn for 1080 degrees which is the nearest multiple of 360 rounded up from the actual duration of one cycle. That is why around 943 degrees in the plot above, the chamber is closed and the fluid within the chamber is shown to be at a constant pressure. While comparing the GT model results to test data, it is important not to consider the portions of the 1080 deg duration plotted here which are not part of the actual cycle.

If a bearing model was chosen, the relevant results to look at within GT-POST is within the OutputRLTs part. The breakdown between Fluid (Indicated) Power and Friction Power can be seen here.



Data can be exported by right-clicking specific plot title.



5 Summary

This document describes the steps to set up and calculate of thermodynamic performance predictions using integrated GT-SUITE solver. More detailed information on using SCORG can be found in the user guide (SCORG, 2019). Thermodynamic calculations are used as the preliminary performance predictions which could be utilised for the design of screw machines, initial conditions for CFD and FEM.

6 Bibliography

Rane, S., 2015. *Grid Generation and CFD analysis of Variable Geometry Screw Machines,* London: City University London.

SCORG, 2019. *SCORG, User Help Manual,* London: City University.

Stosic, N., Smith, I. K. & Kovacevic, A., 2005. *Screw compressors: Mathematical modelling and performance calculation, ISBN 3540242759.* 1 ed. London: Springer.

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