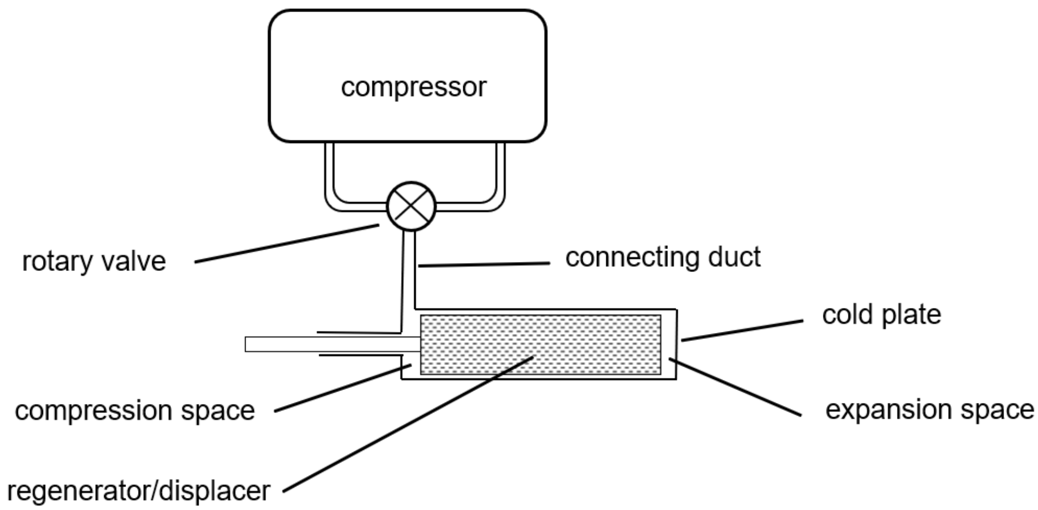
Sage Model Notes

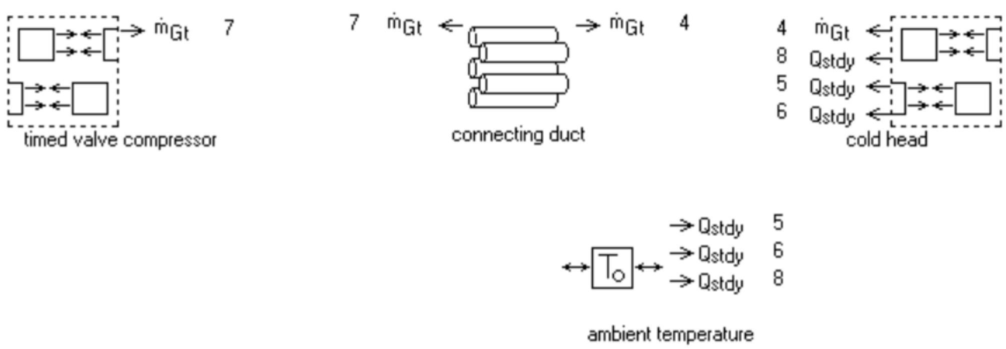
GMSingleStageTimedValvesMovingRegen.scfn

D. Gedeon
27 January 2025

A traditional moving regenerator/displacer GM cryocooler with a volumetric-flow compressor and timed valves providing the cold-head pressure boundary condition. The model schematic looks like this:



The model is organized into submodels with the root-level model looking like this:



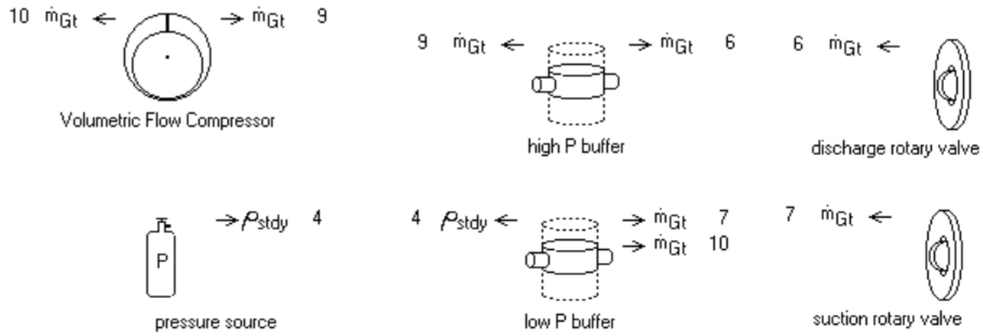
The root model summarizes performance with these user-variable outputs:

```
Qlift          net heat lift                            1.000E+00
  Qstage1
Wcompressor    compressor input power                   2.380E+02
  -Wadiabatic
Qrej           net heat rejection                       2.401E+02
  Qamb + Qduct + QHPbuf + QLPbuf + QDSbuf + Qseal
```

Values for `Qstage1`, `Wadiabatic`, `Qamb`, `Qduct`, `QHPbuf`, `QLPbuf`, `QDSbuf`, `Qseal` come from user-defined variables of lower-level model components.

Compressor

The compressor submodel contains a volumetric flow compressor (a new Sage v13 component) with its flow modulated by time-dependent valve components



The Volumetric Flow Compressor component represents a high level abstraction that characterizes a compressor according to these inputs:

Efficiency	adiabatic efficiency (NonDim)	8.000E-01
Rclearance	relative clearance volume	1.000E-01
Vdot	volumetric flow rate (m3/s)	1.000E-03

Vdot represents the compressor volumetric displacement times the frequency, Rclearance represents the ratio of gas clearance volume at the end of the compression process relative to the volume at the beginning, and Efficiency represent the ratio of ideal adiabatic compressor power input relative to the required mechanical input power. Efficiency is generally less than one because of leakage losses and heat transfer out of the gas. As Rclearance increases it reduces the maximum pressure at the compressor exit, like a real compressor. More details are found in the Sage User's Guide.

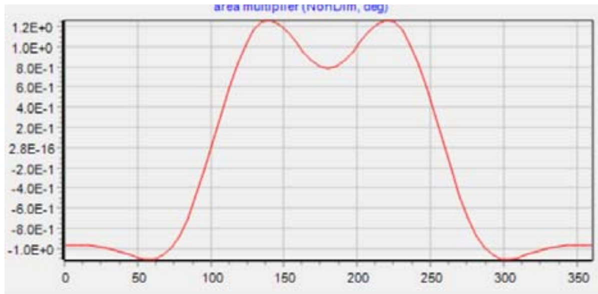
The timing of the rotary valve components is regulated by these inputs.

Discharge rotary valve

OpenFrac	fraction cycle valve open (NonDim)	3.500E-01
Phase	valve timing phase (deg)	0.000E+00

Suction rotary valve

OpenFrac	fraction cycle valve open (NonDim)	4.500E-01
Phase	valve timing phase (deg)	1.800E+02

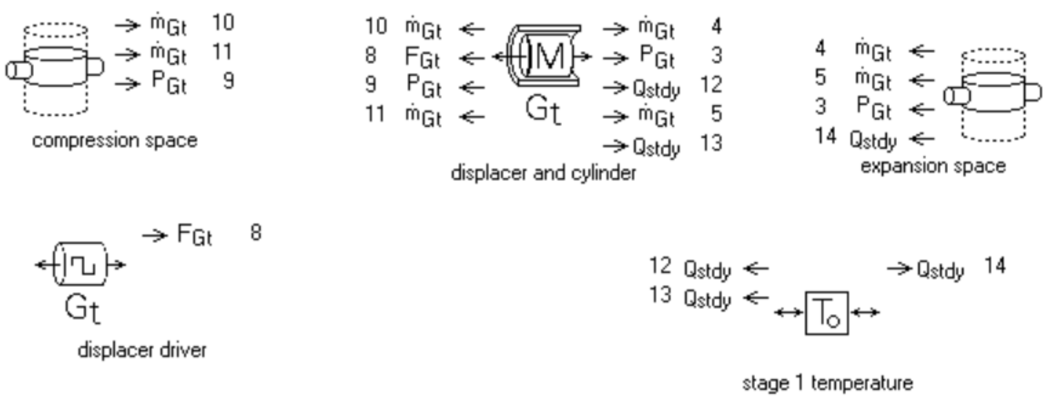


Values greater than 0 in the plots correspond to the times the valves are open. The plotted variables are the interpolated views of recast inputs `Frestrict`, set according to math discussed in the documentation for the related model GMSingleStageSquareWaveValves.scfn.

The discharge valve zero phase establishes the phase reference for the entire model. The suction valve phase is 180 degrees, which means the midpoint of its open time is a half cycle out of phase that of the discharge valve. The phasing of the displacer in the cold head (see below) is the main input that determines the thermodynamic efficiency of the stirling cooling cycle.

Cold Head

The cold-head submodel is much like the model for the cold head of a split-cycle stirling cooler, comprising a composite free-piston and cylinder component (renamed displacer and cylinder) representing the regenerative displacer moving within an outer pressure wall, including provisions for seal leakage and appendix-gap losses:



An abstract constrained-piston component (renamed displacer driver) forces the displacer to move with a defined waveform. The model contains no details about the specific mechanism that moves the displacer.

Model Specific Inputs A number of user-defined inputs and dependent variables defined at the cold-head submodel level provide values for recasting inputs of lower-level model components inside.

inputs

Mdis	displacer mass (kg)	1.000E-01
XdAmpDesign	displacer amplitude (m)	7.135E-03
XdPhsDesign	displacer phase (deg)	3.300E+01
IDcoldfinger	displacer running surface (m)	5.000E-02
Drod	displacer rod diameter (m)	5.000E-03
Lregen	regenerator length (m)	1.500E-01

```
ThkPwall        pressure wall thickness (m)             5.000E-04
ThkRwall        regenerator wall thickness (m)          1.000E-03
GapAppendix     radial appendix gap (m)                 2.000E-04
GapSeal         clearance seal gap (m)                  2.500E-05
EccenSeal       eccentricity seal 0 to 1 (NonDim)       5.000E-01
```

Dependent Variables

```
Adis            displacer area                          1.963E-03
  0.25*Pi*Sqr(IDcoldFinger)
Arod            rod area                                1.963E-05
  Pi/4 * Sqr(Drod)
EccenFac        effective eccentric gap ratio           1.112E+00
  Power(1 + 1.5*Sqr(EccenSeal), 1/3)
```

For details, you can trace dependencies for the above variables under the Tools | Explore Custom Variables dialog.

Cold Temperature The file is currently set up for a cold-end temperature of 40K, which is established by the *T* input of the *stage 1 temperature* heat source. That temperature anchors the temperature of *the expansion space* wall as well as the cold ends of the thermal conduction walls in the *displacer and cylinder* component. Those walls are combined into the conductive surface inside the *appendix gap.*

Optimization

This model implements a simple optimization to minimize the compressor power input to achieve 1.0 W of net cooling power (based on root level outputs `Qlift` and `Wcompressor` shown above).

The optimized variables are:

variable	**definition**	**value**
`Vdot`	Compressor volumetric flow rate (m^3/s)	8.64E-04
`XdAmpDesign`	Displacer amplitude (m)	7.14E-03
`XdPhsDesign`	Displacer phase (deg)	3.30E+01
`IDcoldfinger`	Pressure wall ID (m)	5.00E-02
`Lregen`	Regenerator length (m)	1.50E-01

The constraints governing the optimization are:

1. `Vdot > = 0`
2. `XdAmpDesign > = 1.0E-3`
3. `IDcoldFinger > = 1.0E-2`
4. `Lregen > = 2.0E-2`
5. `IDcoldFinger < = 0.05`
6. `Lregen < = 0.15`
7. `Qlift = 1.0`

Constraints 1—4 were imposed during initial optimizations when the model was very far from optimal. They could have been removed later but do no harm.

Constraints 5—6 were imposed later to prevent cold finger diameter and regenerator length from growing beyond physically realistic limits.

Constraint 7 determines the net cooling power of the optimized model.