SAGE

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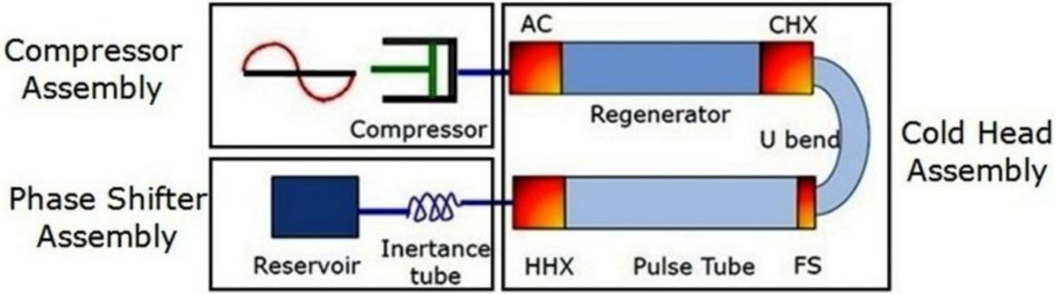
Modelling of a Cryocooler

- The cryocooler is viewed as a serial combination of sub-assemblies
- The sub-assemblies contain different components and constraints as required

Sub-assemblies in a PTC

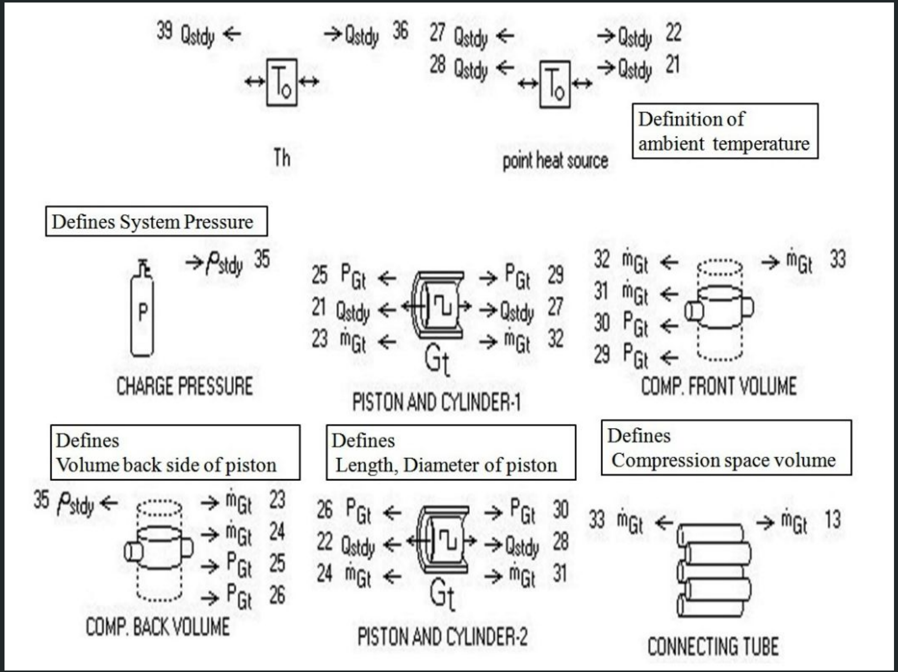
1. Linear Compressor Sub-assembly
2. Cold Head Assembly
3. Phase Shifter Assembly



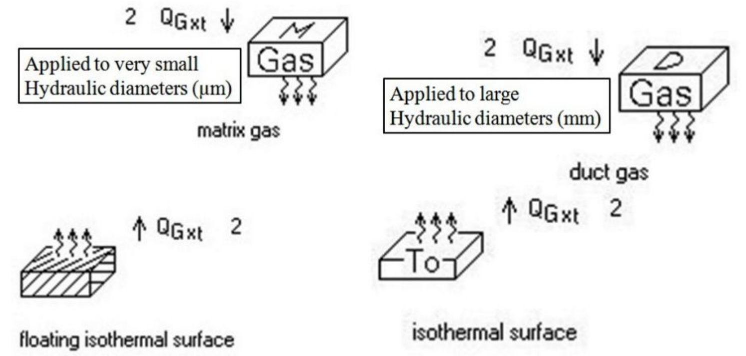
Sub-Assemblies shown in case of a U-Type PTC

1. Linear Compressor

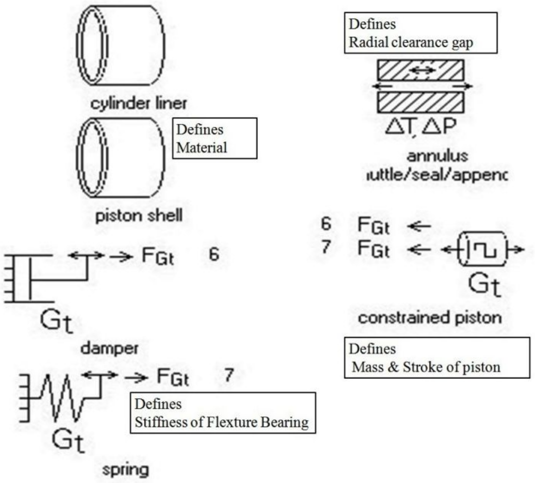
- Linear Motor (not modelled in SAGE, efficiency used in the calculation of input power to the compressor)
- Piston
- Cylinder (and the compression spaces)
- Connecting tube (between this assembly and the cold head)



- Each of the component mentioned in the sub-assembly has to be modelled separately by adding child (sub-sub-assembly) components available on the component palette
- For the Cylinder+Piston assembly, we use a constrained piston which defines mass and stroke. We also use a flexure bearing, defined in terms of spring stiffness; and a clearance between the cylinder and piston
- Within each of the components the type of gas flow and the temperature, force conditions are specified



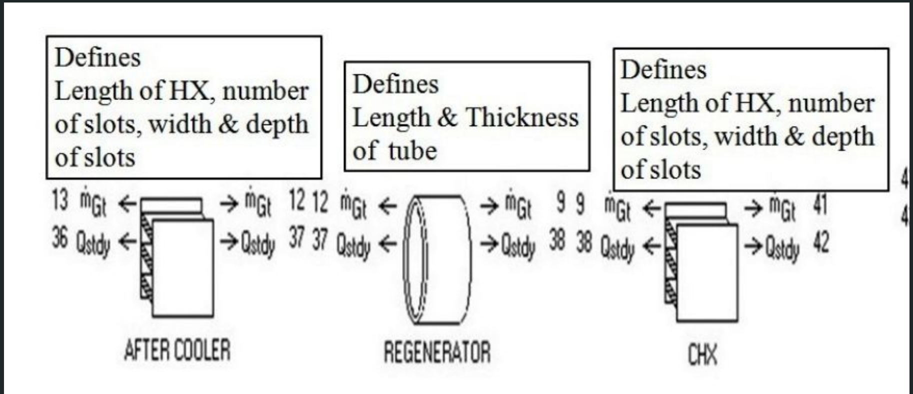
(a) Child component of Annulus Seal (b) Child component of Connecting tube

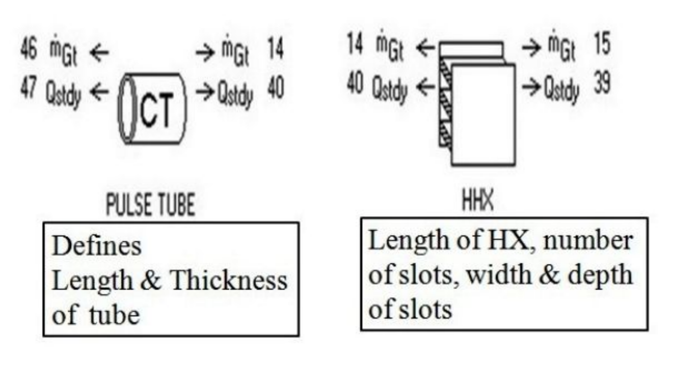


2. Cold Head

The cold head is fitted entirely in a vacuum jacket

- Aftercooler (AC)
- Regenerator
- Cold end heat exchanger (CHX)
- Pulse tube (PT)
- Hot end heat exchanger (HHX)





- The AC, the CHX and the HHX are all heat exchangers modelled in the same way- the transfer heat to or from an external sink or source
- Rectangular finned HX is used, with duct gas (flow of gas through the finned surface), rigorous surface (heat exchange between gas and fins) and distributed conductor (heat exchange between fins and surrounding)
- The regenerator is modelled from a canister containing meshes (matrix- with material, thickness and porosity defined). The heat exchange is shown similar to the one in HX, except matrix gas replaced duct gas
- PT acts as a special component- wherein the empty tube interacts with the gas molecules and also exchanges heat within the gas itself based on the flow regime. Compliance Duct Gas is used in this case which accounts for all the losses

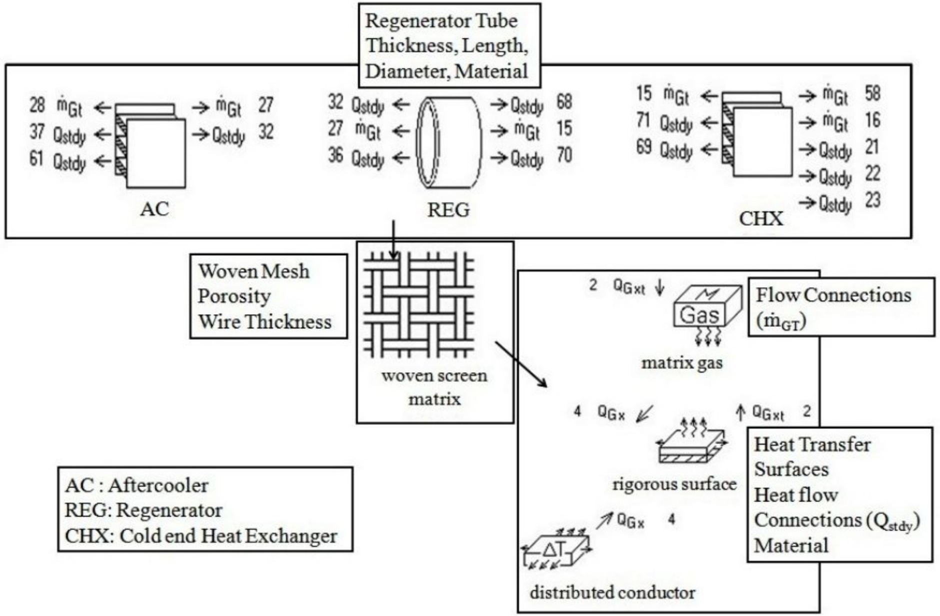


Figure 3.10: Sage model for Regenerator mesh

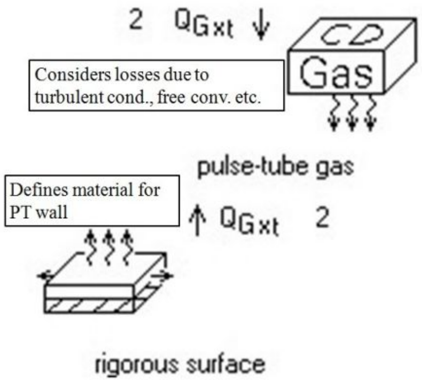


Figure 3.11: Sage model for Pulse tube Gas

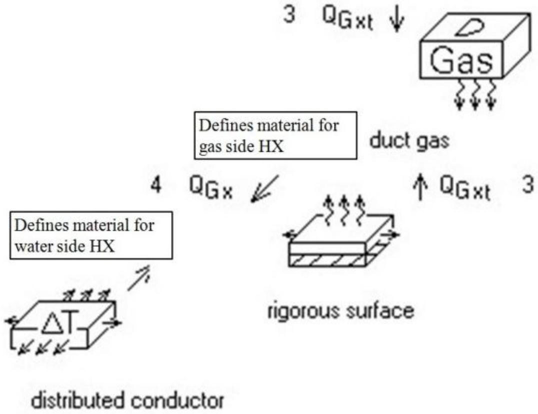
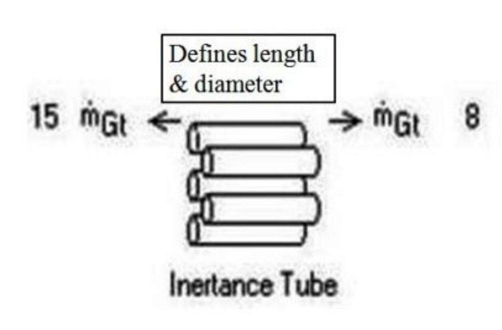
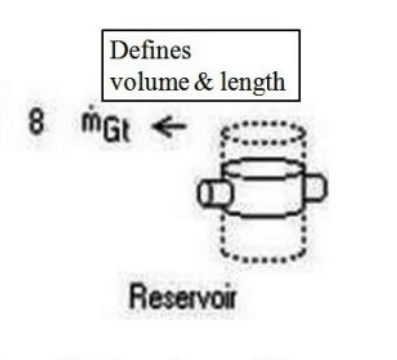


Figure 3.9: Sage model for Aftercooler Assembly

3. Phase Shifter

- Inertance tube- modelled similar to the connecting tube ie with duct gas and isothermal surface
- Reservoir- the assembly ends here





- All the mentioned sub assemblies are connected to form the entire PTC
- The connections are depicted and understood using the matching numbered arrows
- These connections operate under a set of equations, that are solved in SAGE
- Hence we can optimize the conditions are per requirements
- And comparisons between experimental results and SAGE simulation results can be drawn

- **Charge pressure**: acts as infinite isobaric gas reserve
- **Duct gas domain**: used within relatively shorter ducts/tubes with not small D_h
- **Matrix gas domain**: used within a porous matrix, or uniform channels with tiny D_h
- **Compliance duct gas domain**: used in pulse tube, take into account the convective losses that take place due to axial temperature gradient
- **Point heat source**: to specify ambient temperature by attaching steady point heat flow connections
- **Isothermal surface**: functions as isothermal HX surface
- **Floating isothermal surface**: to specify gas temperature within a variable volume space
- **Rigorous Surface**: for modelling duct wall or regenerator matrix
- **Constrained piston**: displacement is the input and the force required is the quantity found during solving, it is usually connected to spring+damper
- **Annulus seal**: to model gas flow through the clearance
- **Distributed Conductor**: models 2D conduction path, used when the conductivity varies significantly over the length of the component

- Q_{stdy} : Steady heat flow
- P_{gt} : Time ring pressure attachment, acting on an area face
- $\dot{m}_{gt}$: Mass flow rate
- ϱ_{stdy} : Common mass density between a gas domain and a reservoir ie they share common mean pressure
- Q_{gxt} : Space-time heat flow, connecting thermal solids to gas domains
- F_{gt} : Time ring force attachment, acting on a point

time ring: a periodic time grid