Sage Model Notes

CoAxPTRRadialInteraction.ptb

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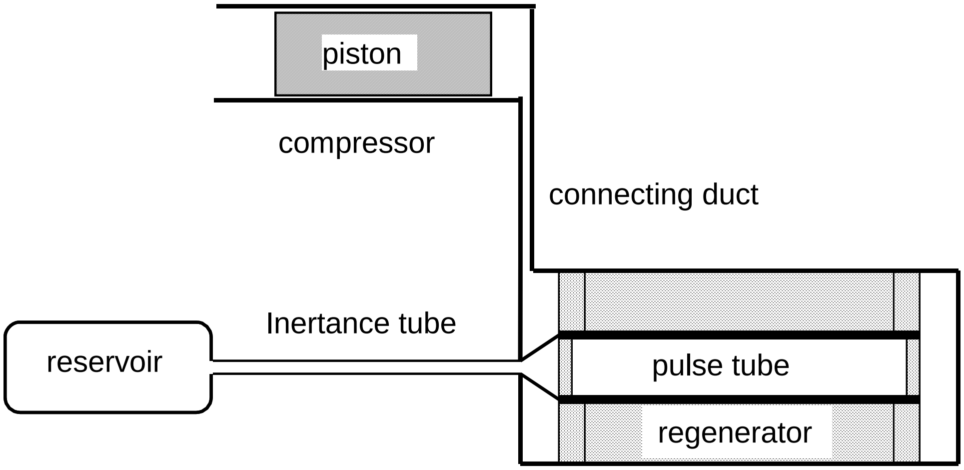
A variation of model CoAxPTR.ptb, that models the radial thermal interaction between the pulse-tube wall and regenerator matrix in a single-stage pulse-tube cooler with pulse-tube arranged co-axially within an annular regenerator. The physical layout is the same as for the model CoAxPTR.ptb:



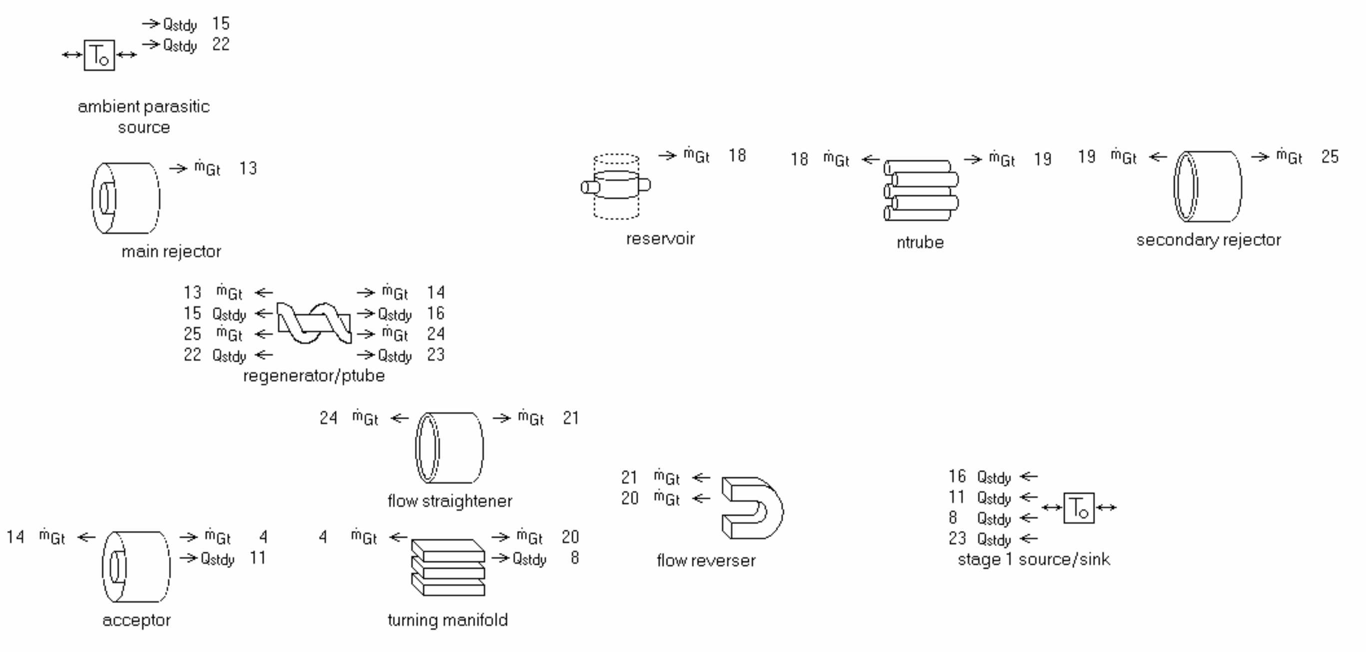
This model derives from the CoAxPTR model and inherits most of its structure except for the packaging of the regenerator and pulse tube within the cold head. This document discusses only the new features compared to the CoAxPTR model and is a supplement to the original documentation found in file CoAxPTR.pdf.

Cold Head Radial Conduction Features

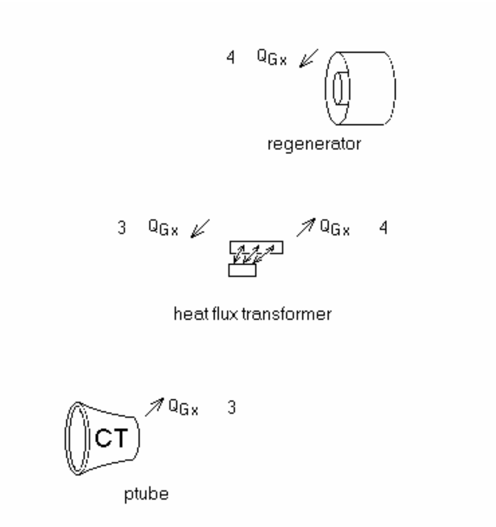
In the original CoAxPTR model there was no way to model a radial thermal interaction between the pulse-tube wall and regenerator matrix because the components were arranged end-to-end in series for helium flow purposes. That meant that the temperature gradients in the regenerator and pulse tube were in opposite directions and a transverse (radial) thermal connection would have resulted in the cold end of the pulse tube exchanging heat with the warm end of the regenerator and vice-versa.

The present model introduces a *flow reverser* between the *turning manifold* at the cold tip and the *flow straightener* at the pulse-tube entrance. Flow reversers were introduced into the pulse-tube model class as of Sage version 6. Their purpose is to switch the flow direction so the positive flow end of one component can be connected to the positive flow end of another, or the negative end to the negative end.

The revised cold head model looks like this:

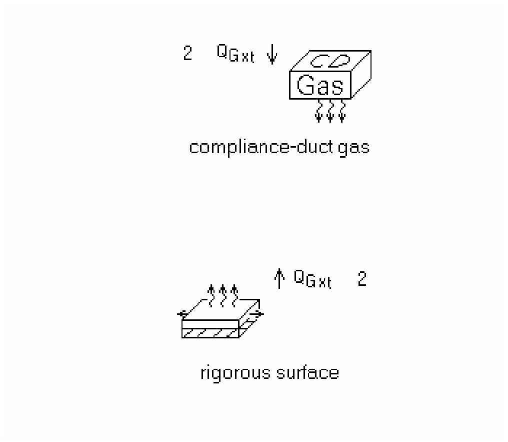


The regenerator and pulse-tube are housed within the multi-length container *regenerator/ptube*, which looks like this inside:



The *heat flux transformer* permits radial thermal conduction (Q_{Gx}) between the pulse tube wall and regenerator matrix. The pulse tube is presumed to be the inner regenerator wall in direct contact with the matrix. The pulse tube and regenerator lengths should be similar to make physical sense although this is not enforced in the model. The radial thermal conduction modeled is the DC heat flow only. Any AC component is filtered out, as is appropriate when thermal penetration depth is small compared to the conduction distance — a reasonable assumption for the relatively long distances involved between the pulse-tube wall and the regenerator interior.

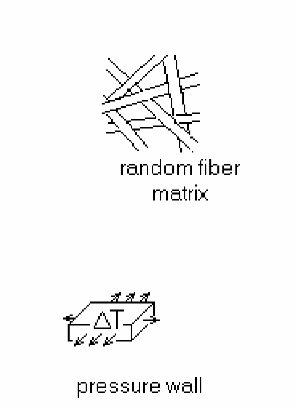
Within the pulse tube the radial thermal conduction originates in the *rigorous surface* representing the pulse tube wall.

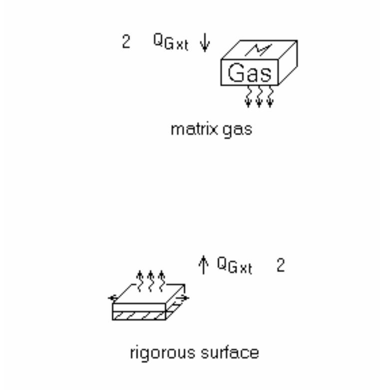


The rigorous surface contains an input *D* which establishes the radial conduction length, in this case the pulse tube wall thickness. In this model the wall thickness varies with length but it is reasonable to use the midpoint for *D* because that is generally a good approximation to the average value and it does not matter much anyway because there will likely be very little radial temperature drop in the wall compared to the regenerator matrix. Accordingly, input *D* is recast in the *rigorous surface* to:

D = Twall(0.5)

Within the regenerator the radial thermal conduction originates in the *rigorous surface* within the random fiber matrix representing the regenerator matrix solid. It does not originate in the *pressure wall*, which in this model represents only the outer regenerator wall.





Setting the appropriate input *D* for the matrix rigorous surface is trickier. In the Sage model the matrix solid is morphed into a rectangular solid with *y*-dimension given by input *D* and *y*-face area consistent with the total matrix solid volume. So setting *D* to the regenerator radial thickness corresponds to Sage modeling conduction along a number of radial regenerator wires that are thermally bonded to the pulse-tube wall. In reality the wires have a random, non-radial, orientation and there may be significant contact resistance at the pulse-tube wall. Also, if the wires are made of an insulating material then the helium surrounding the wires may increase the effective radial conductivity. The only way Sage can deal with any of these real-world complications is by adjusting the value for *D*. In the present model input *D* is recast to radial regenerator thickness for lack of any better information.

D = 0.5 * (Dout - Din)

You can introduce another factor in this expression as needed to represent a tortuous typical wire path or to calibrate the model to actual data.

Affect of Radial Conduction

The presence of radial conduction between the regenerator matrix and pulse-tube wall does not seem to affect performance much. Compared to the same model without the radial conduction there is actually a slight increase in cooling power (factor 1.009), although a slight drop in overall efficiency (PV power input increases by factor 1.013). It appears the main effect of radial conduction is to alter the temperature distributions along the pulse tube wall and regenerator matrix without changing much the thermal losses that result from those temperature distributions.