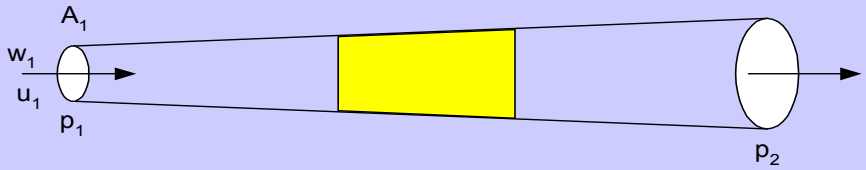
Recollection of first lecture:
There are 3 methods, with which one can reduce the temperature of a refrigerant:

- Heat rejection to an even colder system
- Yesterday: Throttling or mixing
- Today: Performance of work by the refrigerant

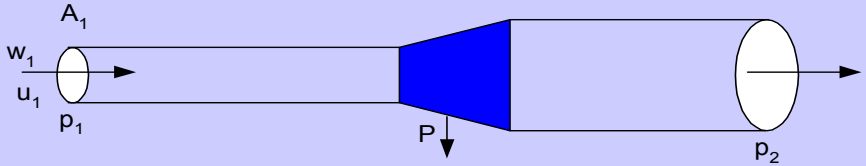
Increase of the cooling effect by replacing the throttle valve by an expander

Energy conservation for an open system with throttling



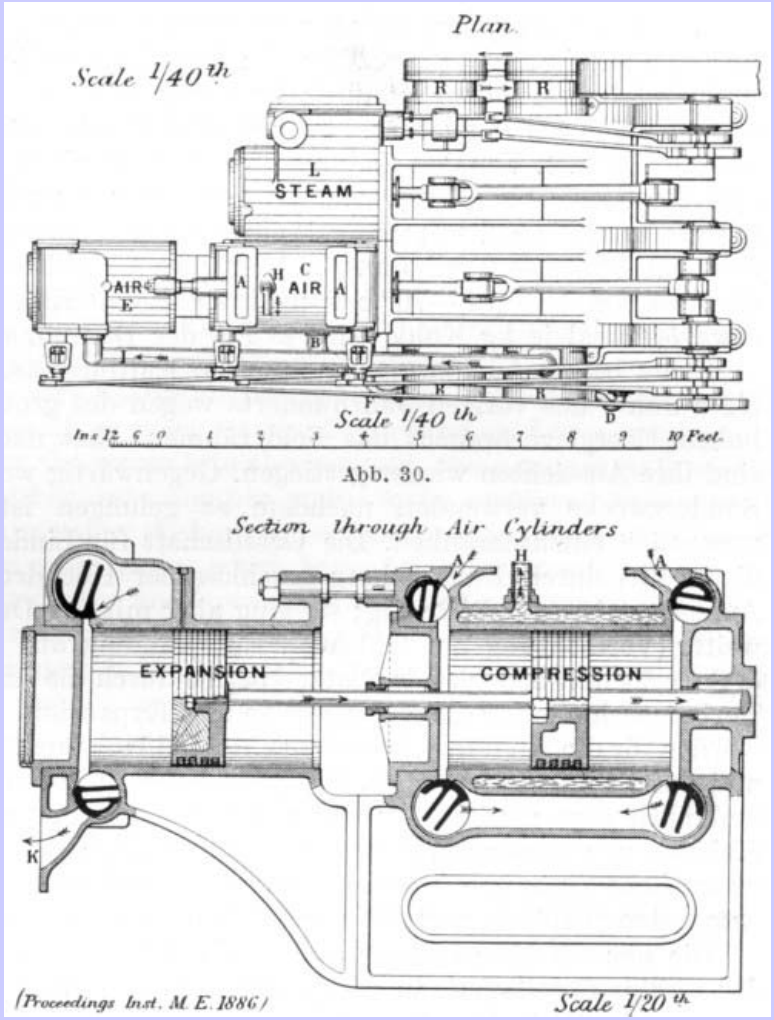
$$h_2 = h_1$$

Energy conservation for an open system with expander

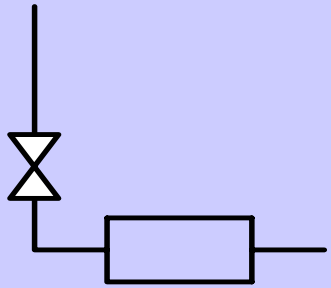


$$h_2 = h_1 - P/m$$

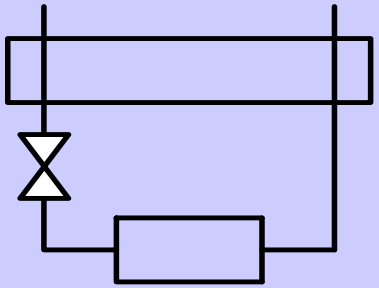
Cold Air Refrigerator (Lightfoot)



Replacement of the throttle valve by an expander

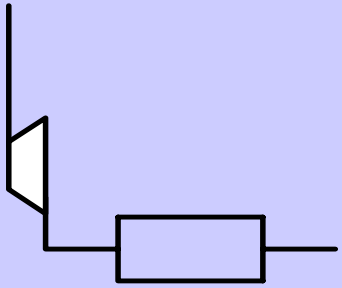


Throttle refrigeration

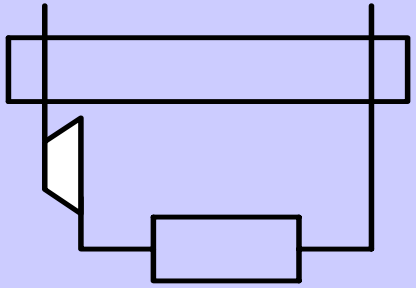


Throttle refrigeration with recuperator

Limited to special region of state properties



Expander refrigeration



Expander refrigeration with recuperator

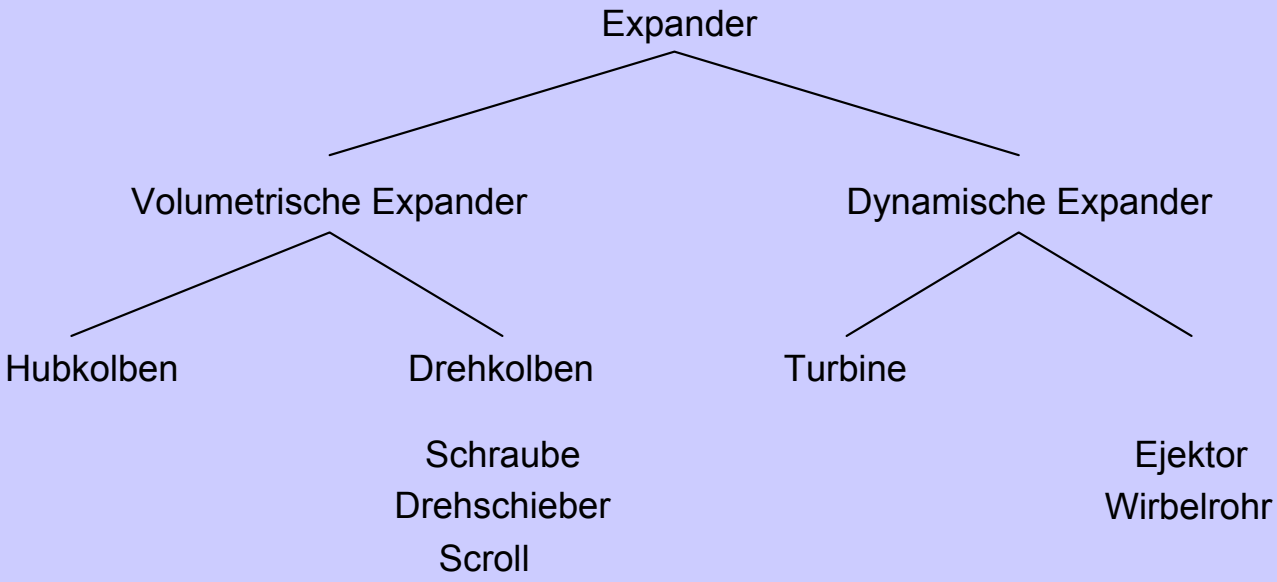
Possible for the whole state area

What is an expander ?

- The expander is a machine, which extracts power from an expanding stream.
- Examples are piston or turbo expanders
- In refrigeration the enthalpy reduction of the refrigerant is more important than the re-use of the power.

The double effect of an expander

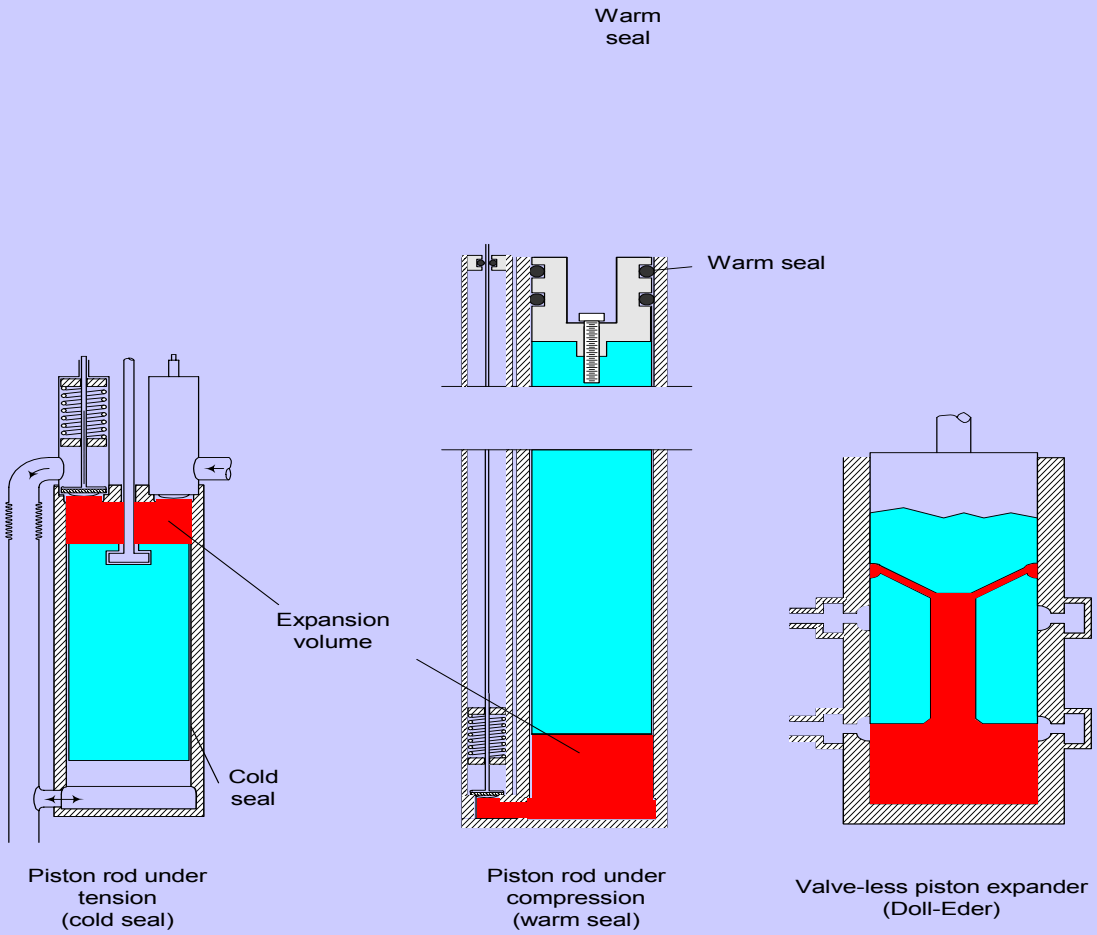
- Production of work plus reduction of enthalpy of working fluid
- What is more important?


Expander
Volumetrische Expander
Dynamische Expander
Hubkolben
Drehkolben
Turbine
Schraube
Drehschieber
Scroll
Ejektor
Wirbelrohr

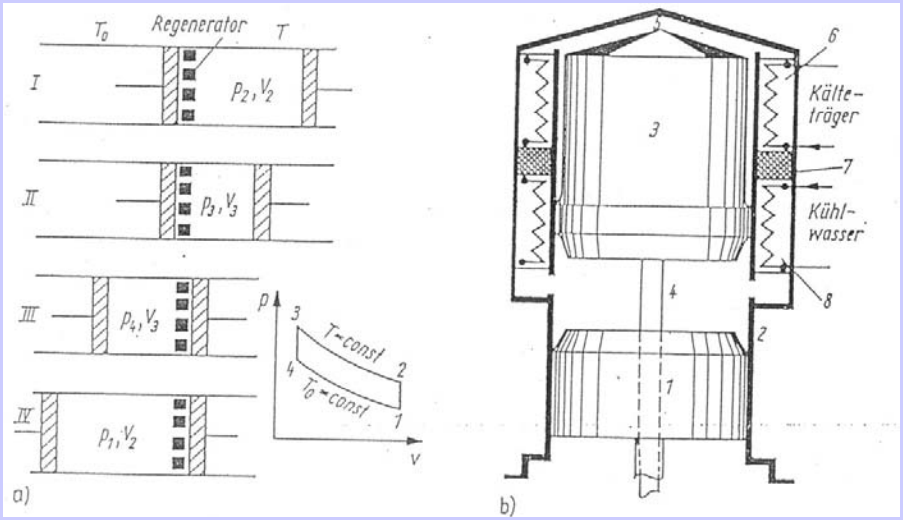
Volumetric Expander	Turbo Expander	Displacer or Gas Piston	Momentum Transfer in Direct Contact
<u>Piston</u> Rotary - screw - scroll - vane	Impulse <u>Reaction</u>	Stirling Gifford-McMahon Pulse tube Acoustic refrigerator	Vortex tube Ejector

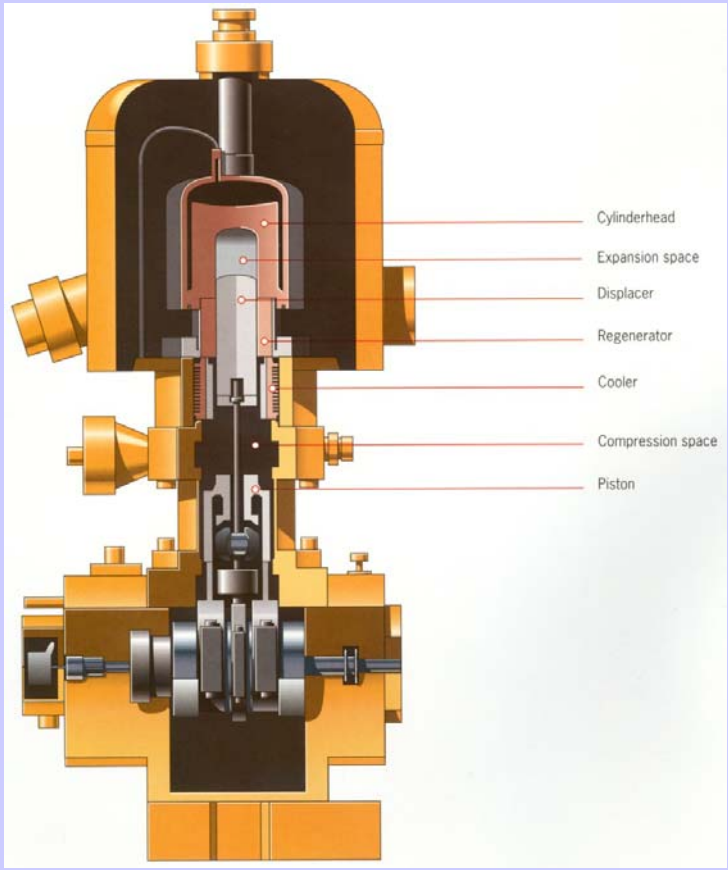
Types of expanders

Cryogenic Piston Expanders



Stirling refrigerator

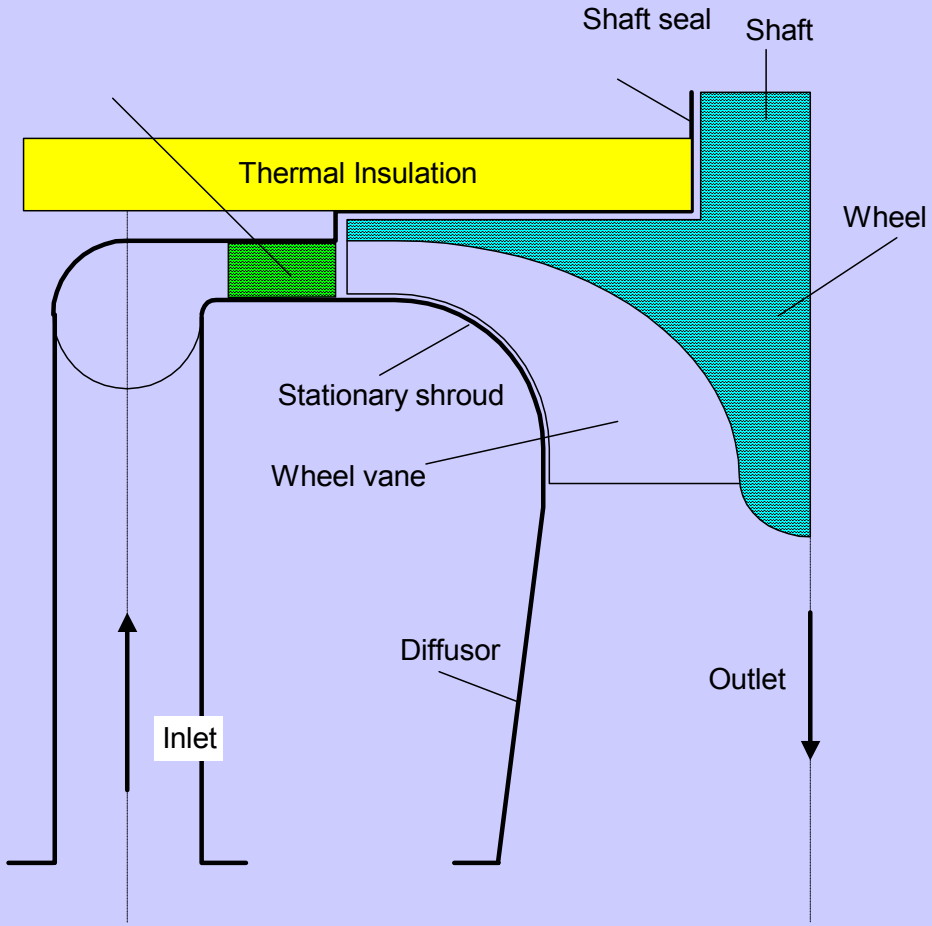




Other volumetric expanders

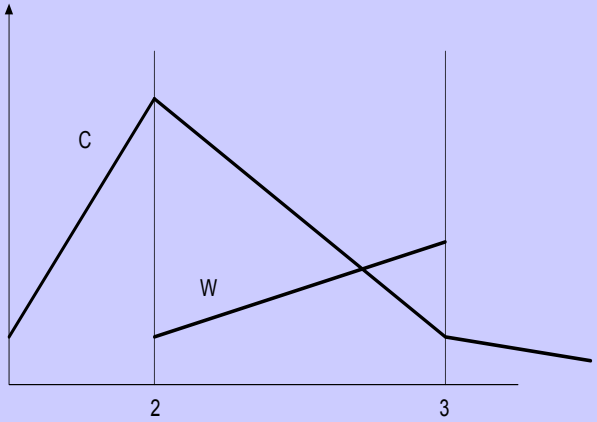
Adavantages and disadvantages of piston expanders (volumetric expanders)

Principle of turboexpander

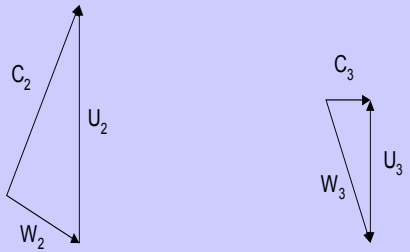

Shaft seal
Shaft
Thermal Insulation
Wheel
Stationary shroud
Wheel vane
Diffusor
Outlet
Inlet

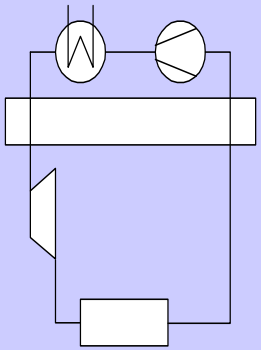
Competing Requirements in Expander Design

	High Reliability	High Efficiency
Clearances	Should be large to avoid contact.	Should be small to avoid leakages.
Length to diameter ratio	Design should be compact for high stiffness.	Design should be slim to reduce heat leak. Overhang design required.

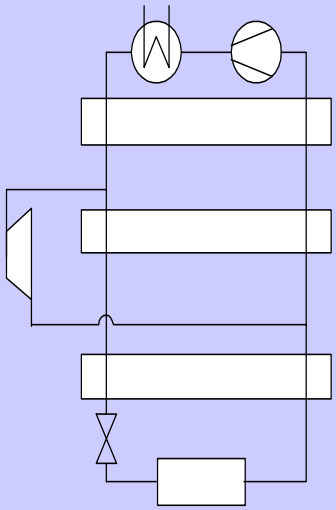


Stator Rotor

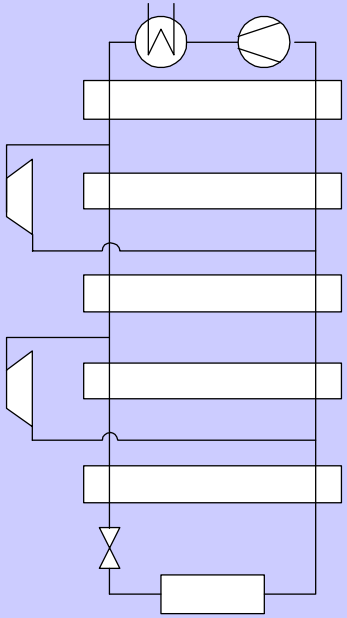




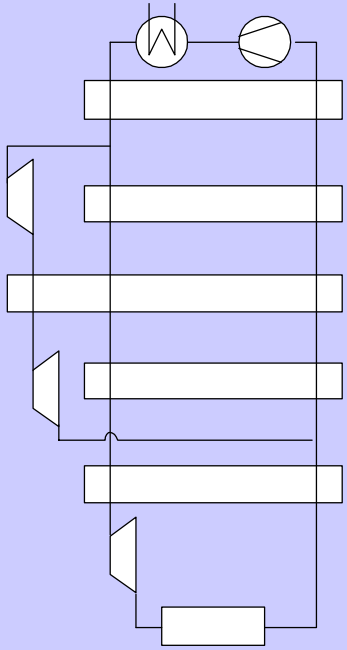
Brayton



Claude



Expanders in parallel
(Collins)



Expanders in series
plus wet expander

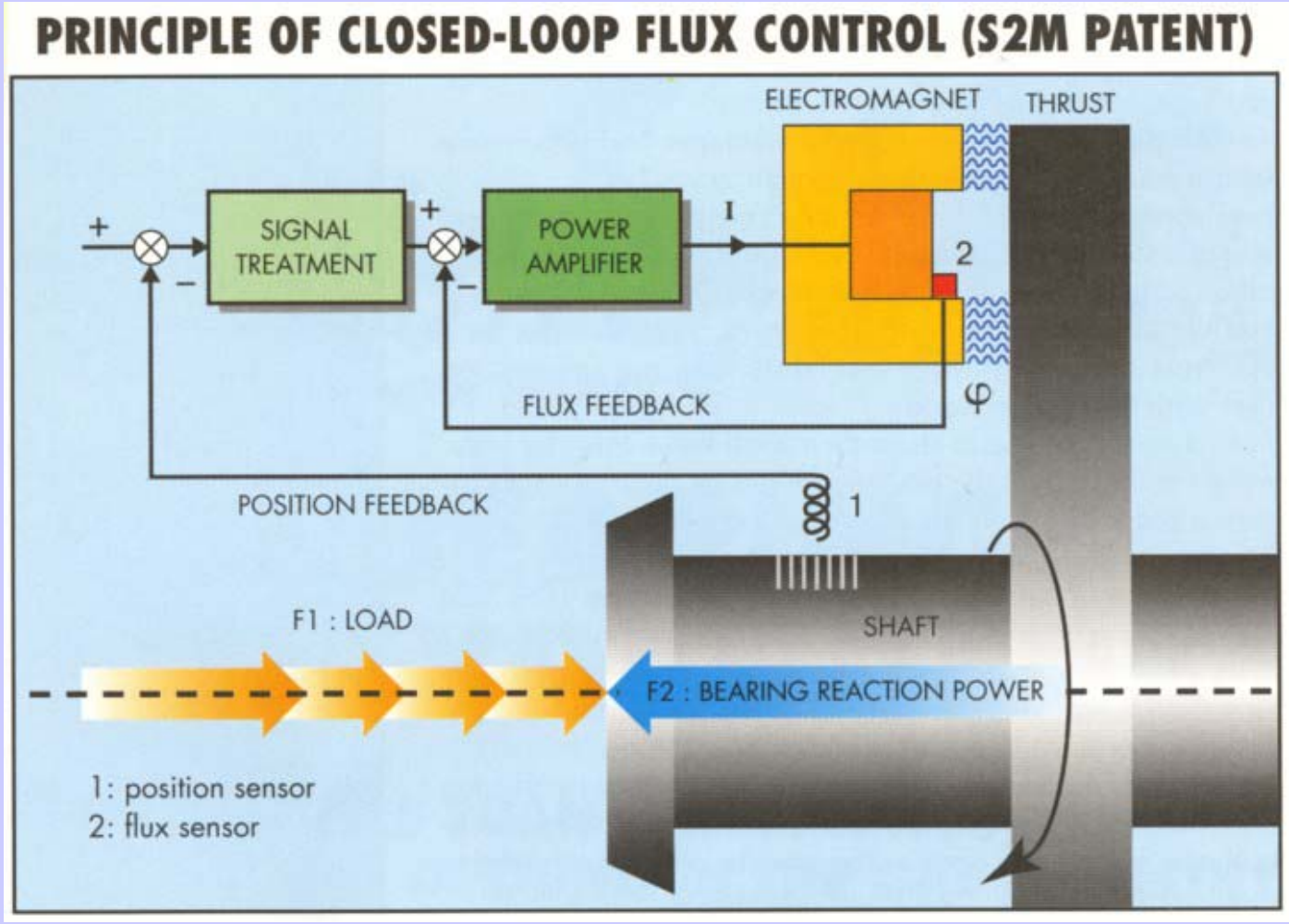
Bearings considered for cryogenic turbomachinery

Type of Bearing	Bearing Load	Specific bearing load	Stiffness
	[kN]	[N/cm^2]	[N/mm]
Hydrostatic oil bearings	10.000	300	300.000
Hydrodynamic oil bearings	8.000	300	300.000
Static gas bearings	80	40	60.000
Dynamic gas bearings	14	20	40.000
Ball bearings	9.000	1.600	200.000
Active magnetic bearings	300	50	600
Superconducting bearings	5	15	200

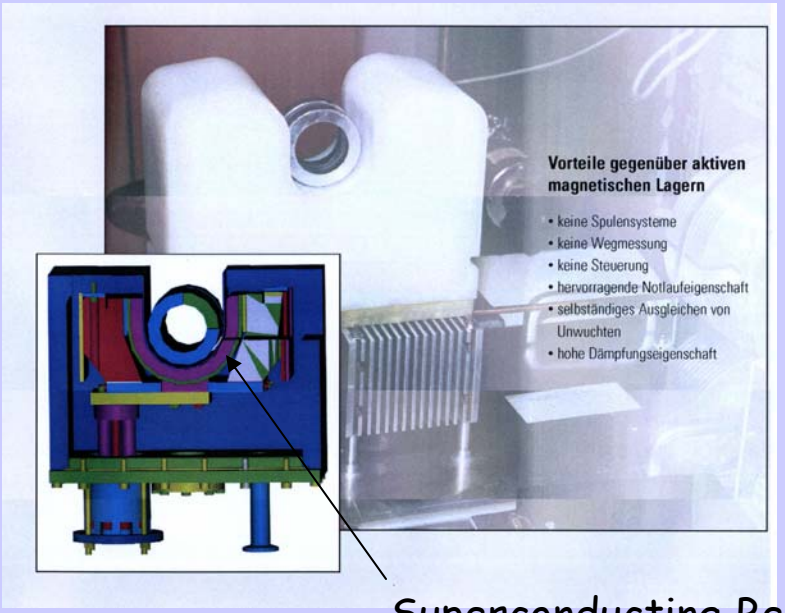
OIL-BEARING TURBOEXPANDERS FOR HELIUM AND HYDROGEN

Oil-bearing turboexpanders

Magnetic bearing turbine



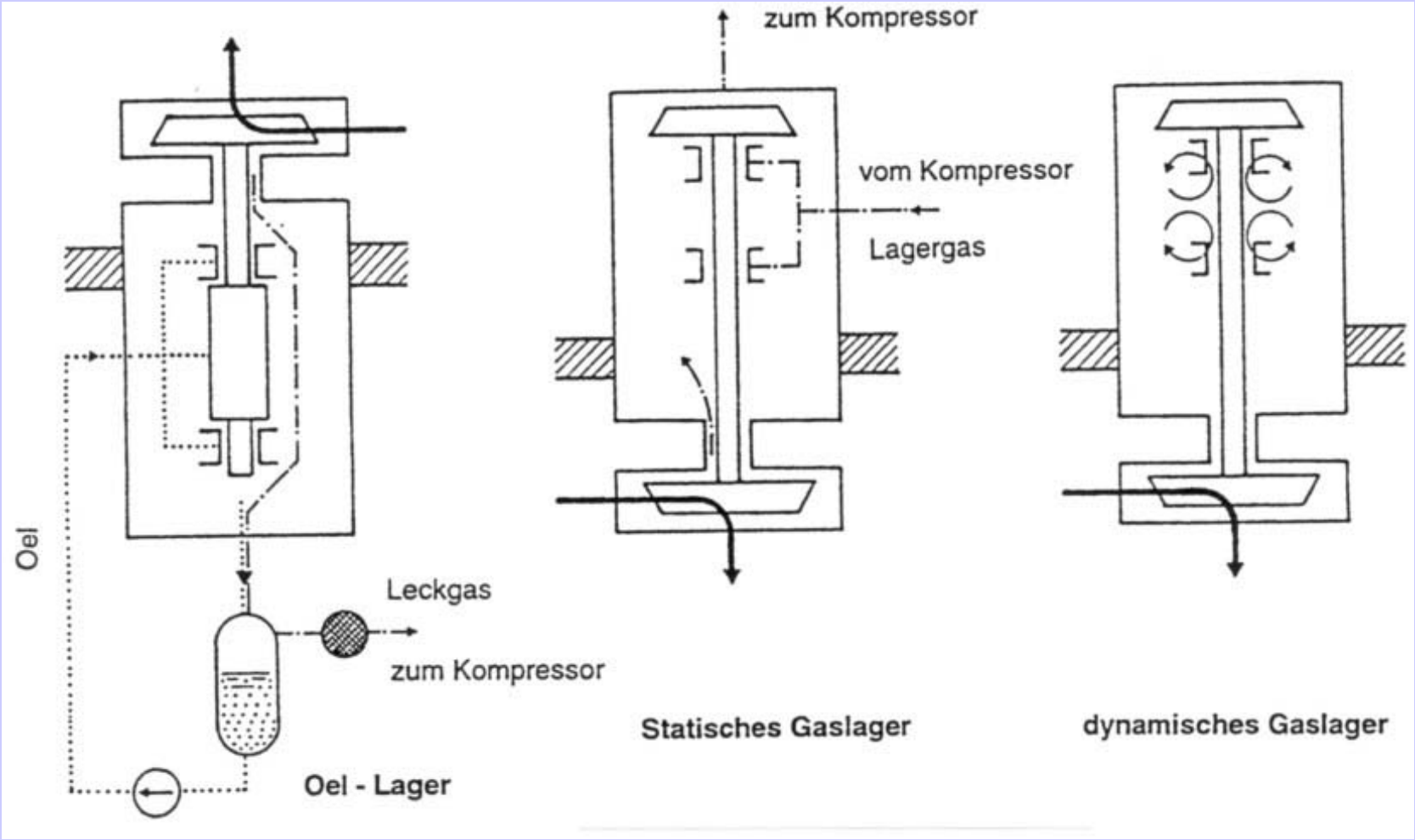
High T_c Bearings

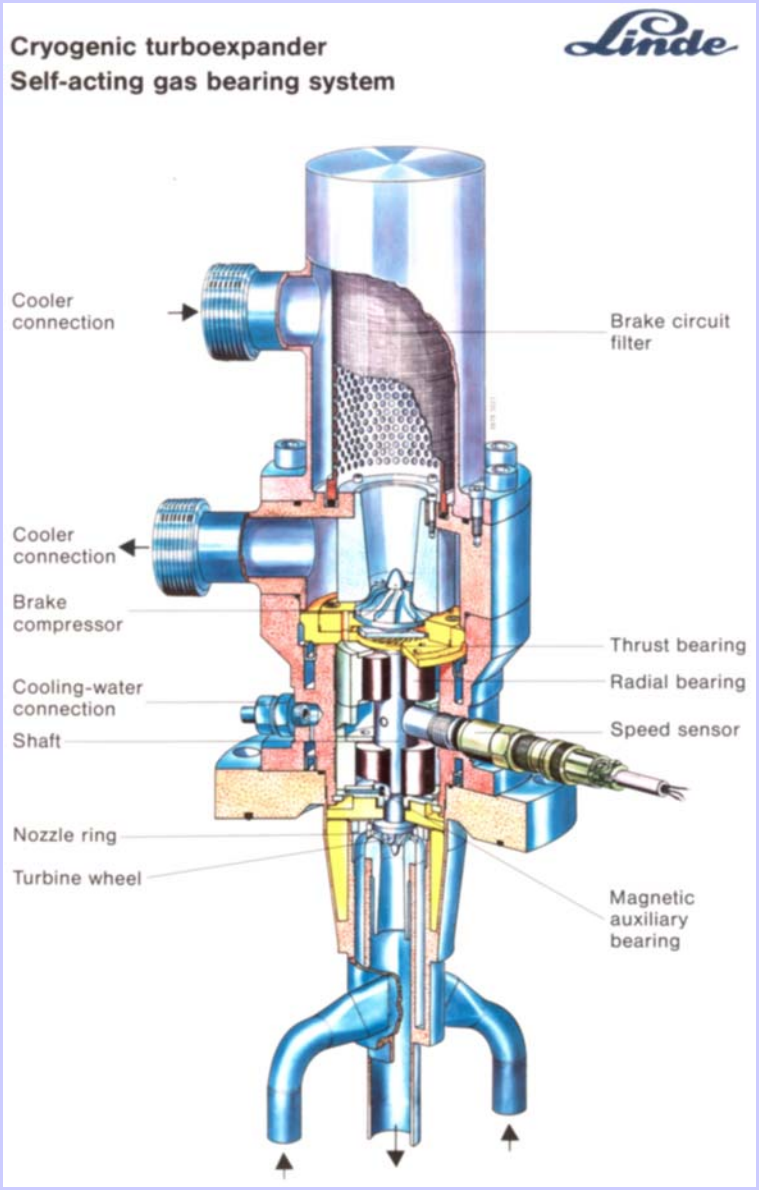


Superconducting Bearing

Bearings to rotate silicon wafers
in an acid bath. Bearings are open
to the top, so that rotor can be removed
(Picture provided by ILK Dresden)

Gas bearing turbines




Cryogenic turboexpander
Self-acting gas bearing system
Linde
Cooler connection
Cooler connection
Brake compressor
Cooling-water connection
Shaft
Nozzle ring
Turbine wheel
Brake circuit filter
Thrust bearing
Radial bearing
Speed sensor
Magnetic auxiliary bearing

- Turbine warm and cold housing

Turbine with static gas bearings (Air Liquide)

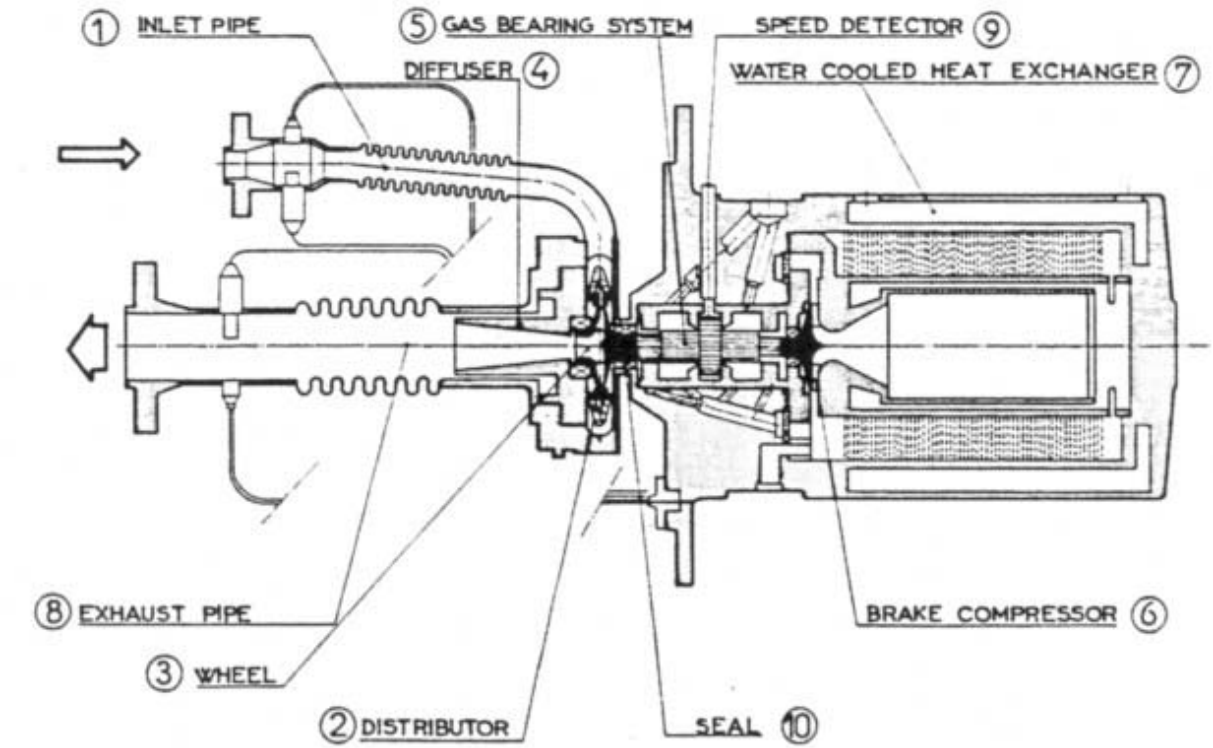


Fig. 1. Gas bearing cryogenic expansion turbine.

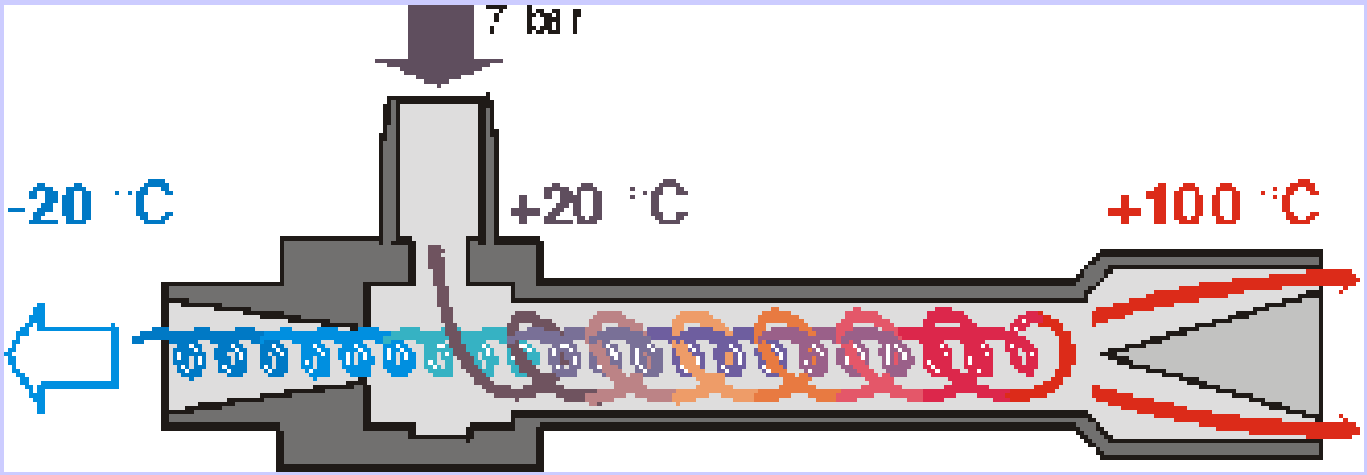
Air Liquide Turbine

Turbine détente cryogénique à paliers gaz.
Gas bearing cryogenic expansion turbine.

The dream of the expander without moving parts

- How can one transfer continuously mechanical power from a (cold) fluid to another (warm) fluid?
- Rotating fluid
- Oscillating fluid

Expander without moving parts: Ranque Hilsch Tube



Pulse Tube (A Stirling Refrigerator with gas piston)

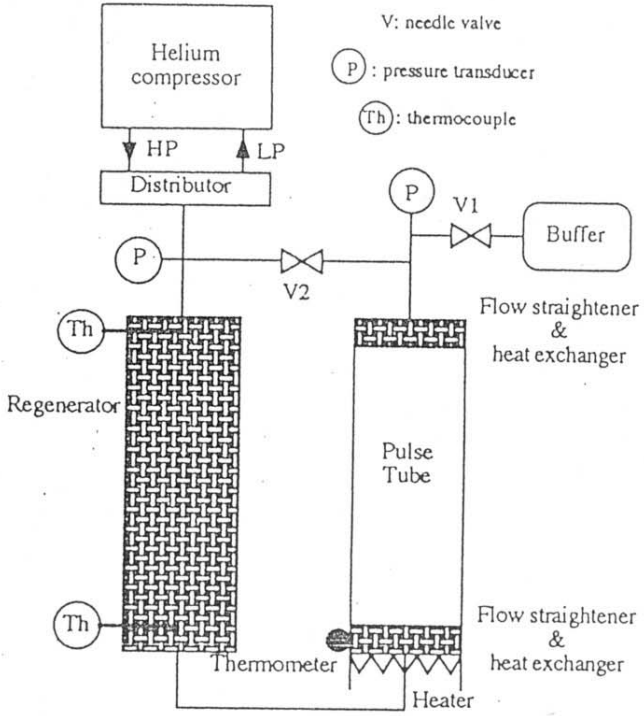


Figure 1: Experimental set-up

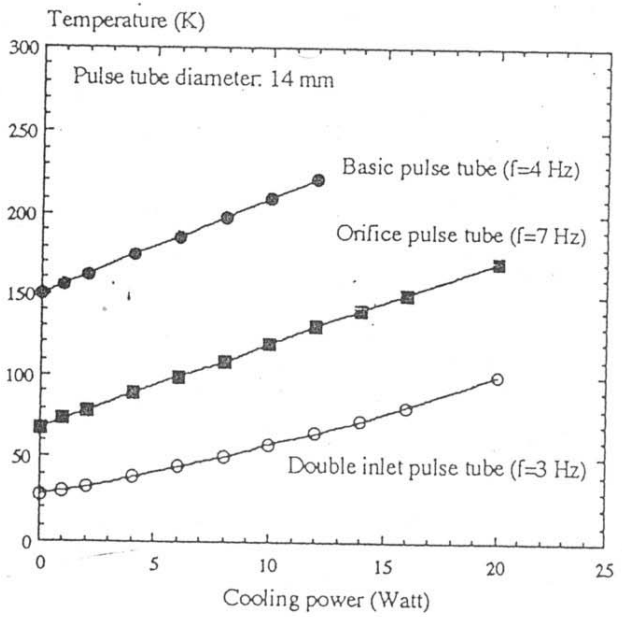


Figure 3: Temperature versus cooling power for various configuration

Moving jet expander

The maximum work from an expander

- There must be a maximum
- Principle of reversibility: process at constant entropy
- Interest mainly in reduced enthalpy not in recovered power
- Throttling has efficiency zero
- Efficiency of expanders dependent on size

Production of refrigeration with expanders (summary)

- Different working principles
- Reduced enthalpy is more important than recovered power
- Gas bearing turbines are the work horse in helium cryogenics
- Still many things to invent, especially in expanders without moving parts

- Thursday: Closing the cycle