Institute for
Thermal Turbomaschinery
and Machine Dynamics

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Conceptual Design for an Industrial Prototype Graz Cycle Power Plant

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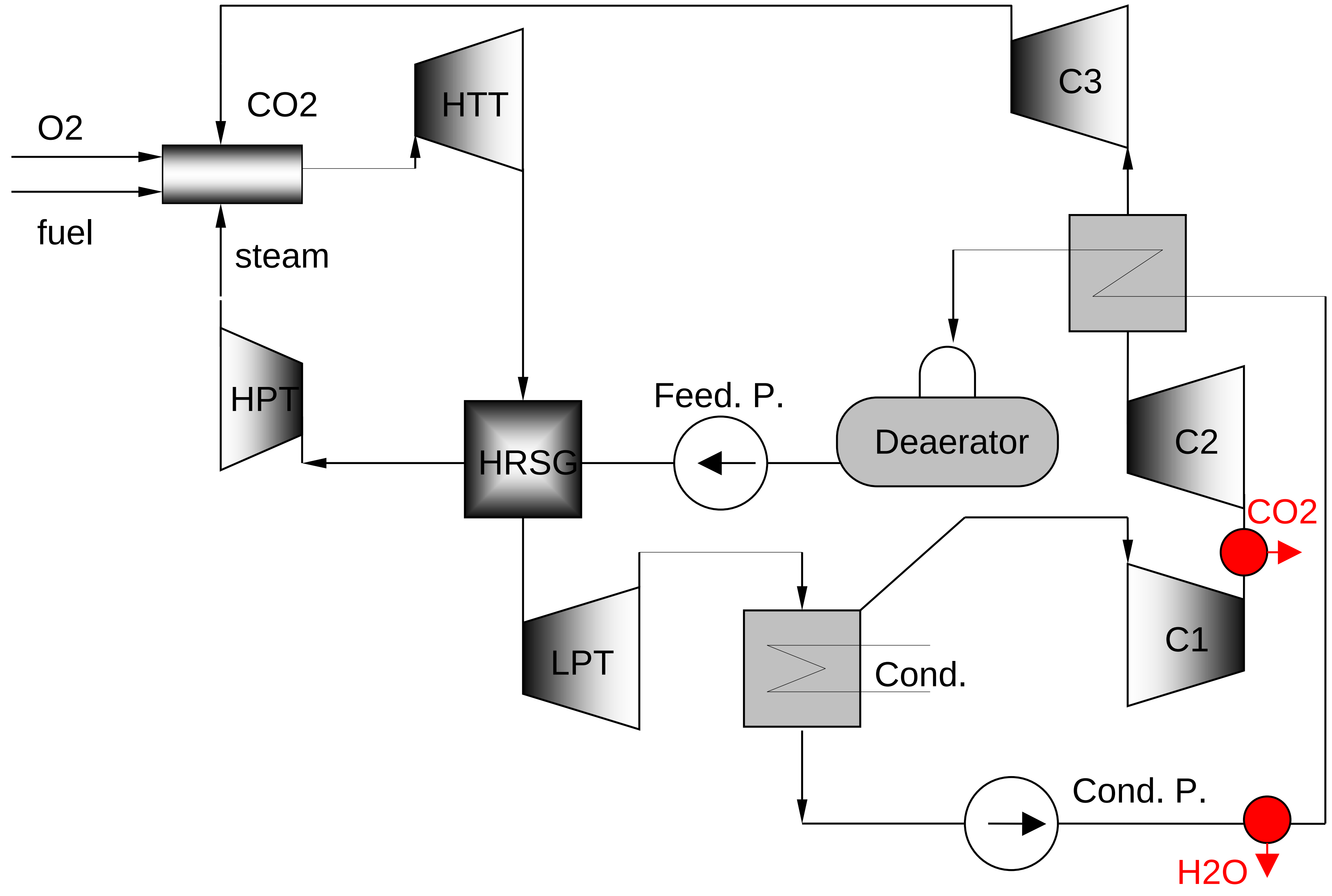
History of the Graz Cycle

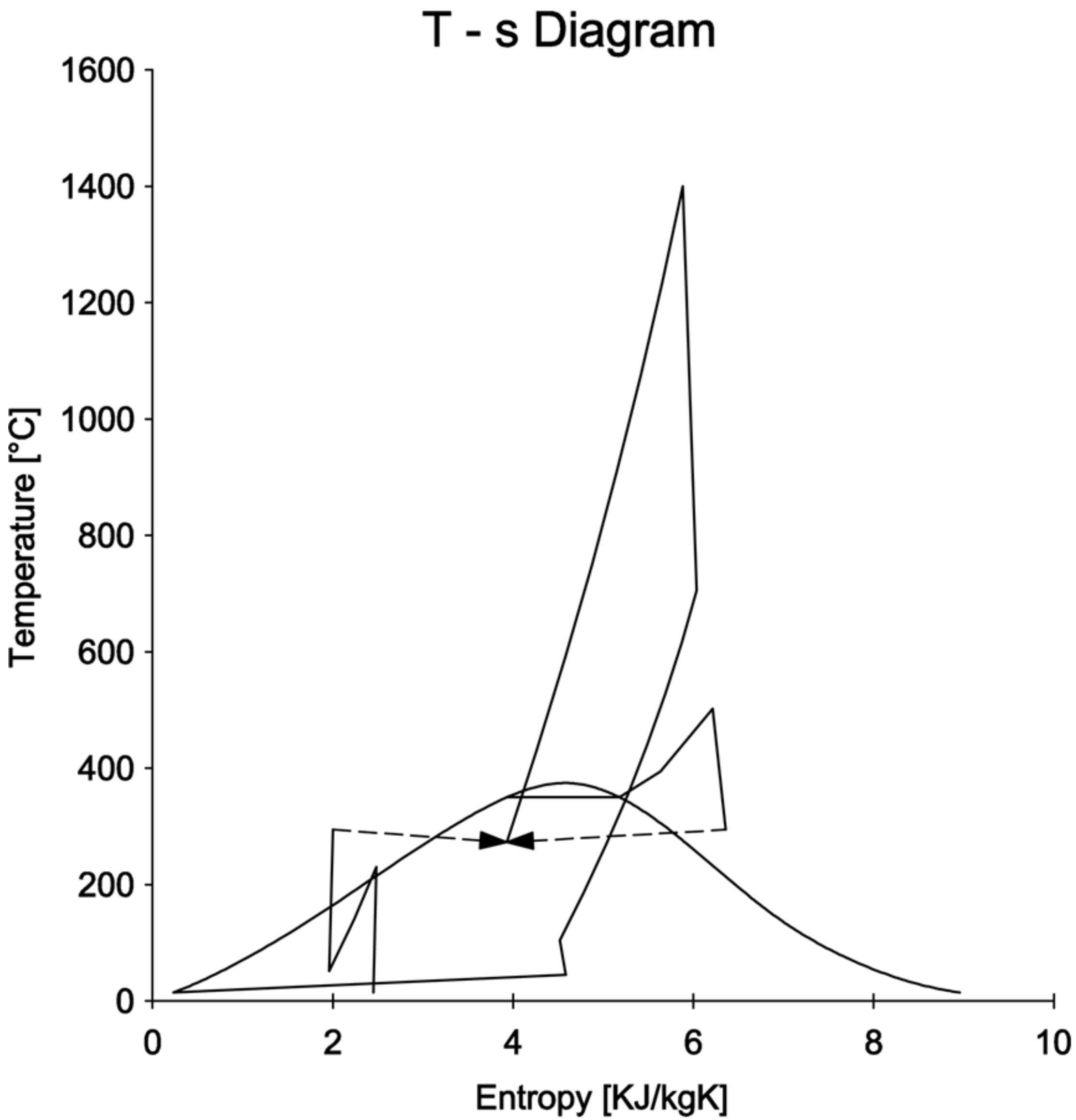
- **1985: presentation of a power cycle without any emission - H_2/O_2 internally fired steam cycle**
- **1989/91: thermodynamic improvement and combustion chamber design**
- **Cooperation with Japanese research institutes and companies - name GRAZ CYCLE defined**
- **1995: change from H_2 to fossil fuels like methane (CH_4)**
- **2000: presentation of thermodynamically optimized cycle for fuel gases from gasification processes**
- **2002: conceptual layout of turbomachinery relevant components of prototype Graz Cycle power plant**

Design Goals of Graz Cycle

- High thermal efficiency similar to modern combined cycle power plants
- Avoidance of any emission to atmosphere, retention of CO2
- Only use of progressively developed gas turbine components
- Use of fossil fuels

Cycle Scheme




T - s Diagram
1600
1400
1200
1000
800
600
400
200
0
Temperature [°C]
0
2
4
6
8
10
Entropy [KJ/kgK]

Balance of Graz Cycle

Turbines				
Name	HPT	HTT	LPT	Total
Power [MW]	9.3	91	10.7	111

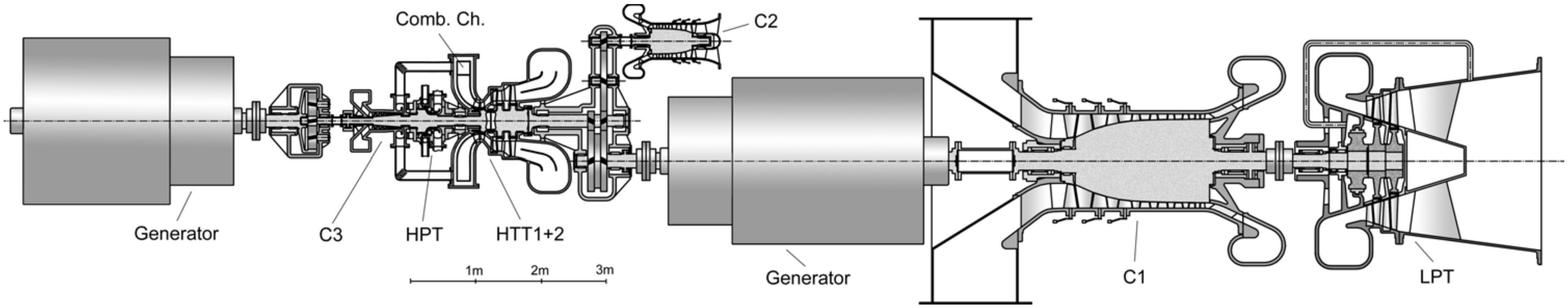
Compressors and Pumps						
Name	C1	C2	C3	Cond.P.	Feed P.	Total
Power [MW]	5.5	4	8.9	0.01	0.4	18.8

- **Total heat input: 143.3 MW**
- **Thermal efficiency: (111-18.8)/143.3 = 63.9 %**
- **Including generator / mechanical losses**
  0.3 kWh/kg O2 production effort (half considered)
  O2 compression to combustion pressure

  Thermal efficiency: 57.5 %

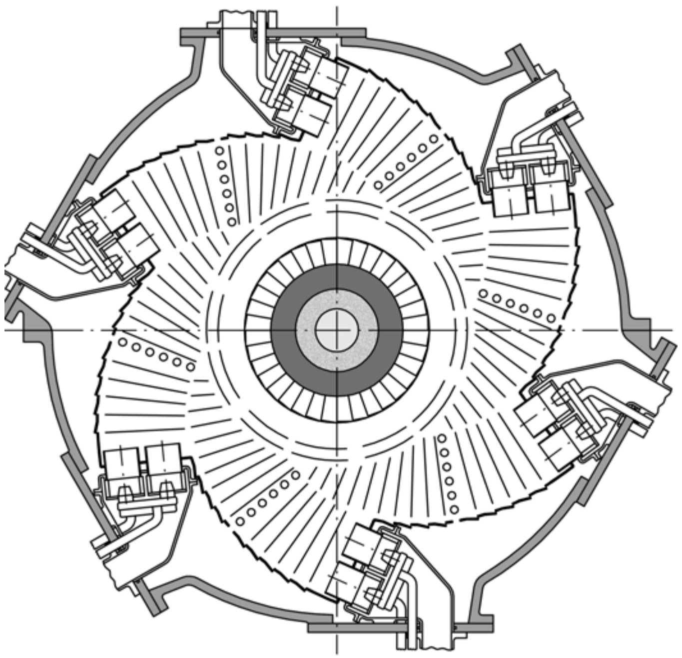
Advantages of Graz Cycle

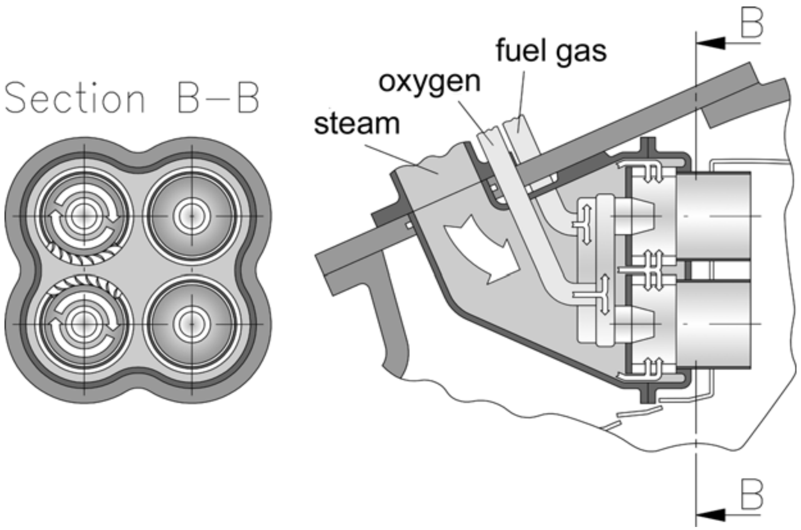
- The high efficiency of the cycle follows mainly from the low compression work, the steam part of the cycle medium is generated from the feed water which can be pumped
- The highest cycle pressure only slightly surpasses the maximum pressure used in aircraft engines
- The highest temperature is similar to temperatures of high power stationary gas turbines
- The cycle medium is a variable mixture of CO2 and H2O, thus allowing CO2 retention by condensation
- The heat exchangers incorporated in the cycle have high temperature differences, thus will lead to low cost HE with limited amount of high temperature tube alloy



Comb. Ch.
C2
Generator
C3
HPT
HTT1+2
1m
2m
3m
Generator
C1
LPT

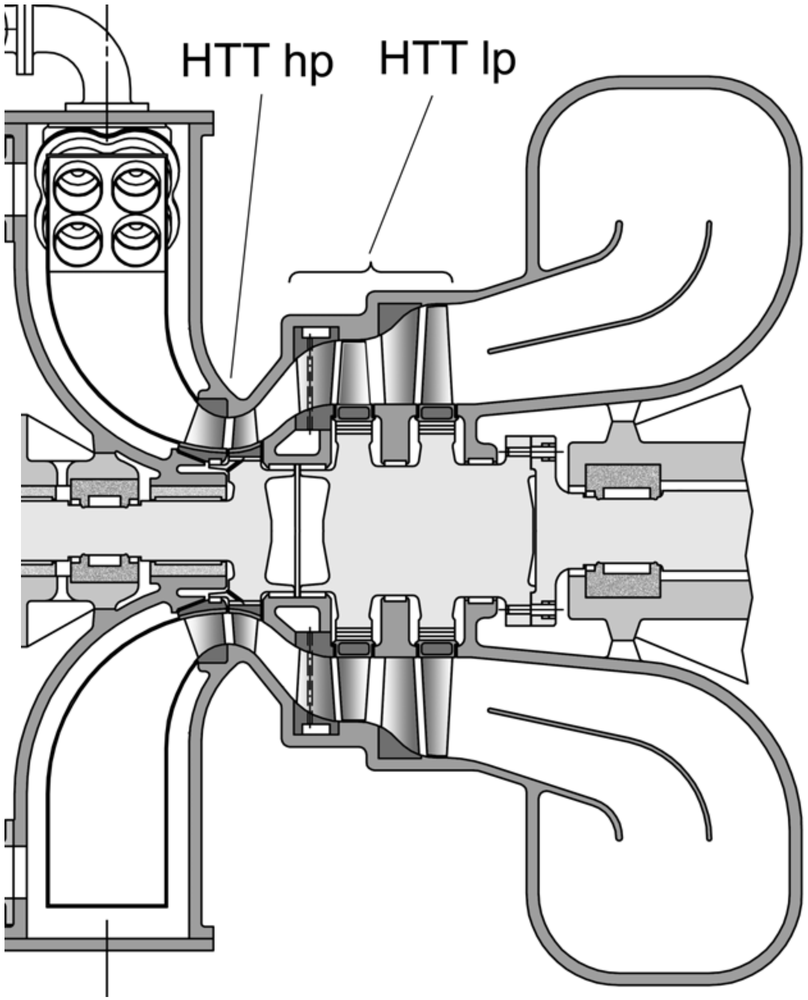
Combustion Chamber Design





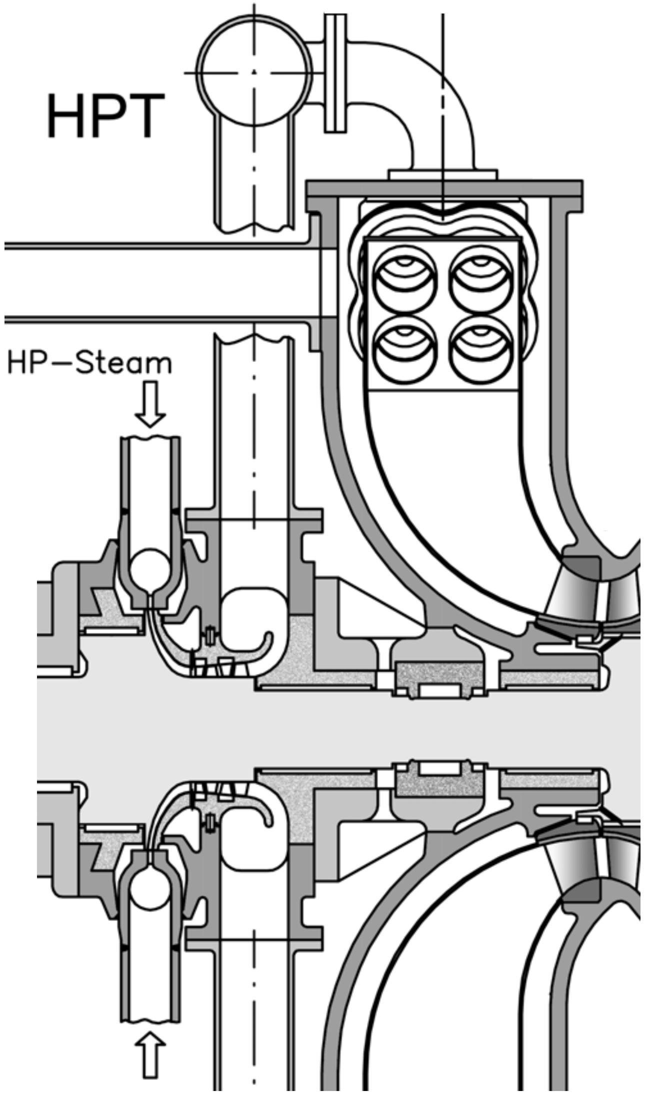
- Stoichiometric combustion of fossil fuel and O2 at 40 bar
- Combustor exit temperature: 1400 °C
- Very low NOx generation (only nitrogen from fuel)
- Annular flame casing with 6 quadruples of burner tubes
- Tangential arrangement provides additional flow path length for better mixture and preswirl for first turbine stage
- Cooling of burner by steam and of liner by CO2
- Steam is fed tangentially into the burner forming a vortex
- Expected vortex breakdown induces strong backflow, thus continuous ignition

High Temperature Turbine HTT



- Pressure drop: 40 bar - 1 bar
- High specific enthalpy drop compared to conventional gas turbines demands high rotational speeds to keep number of stages low
- First stage connected to HP turbine and C3 compressor
  overhang design
  20 000 rpm
  Generator driven via planetary gear box
- 2nd and 3rd stage overhang design carried by pinion of the main gear box
  12 000 rpm
- Steam cooling of blading of 1st and 2nd stage

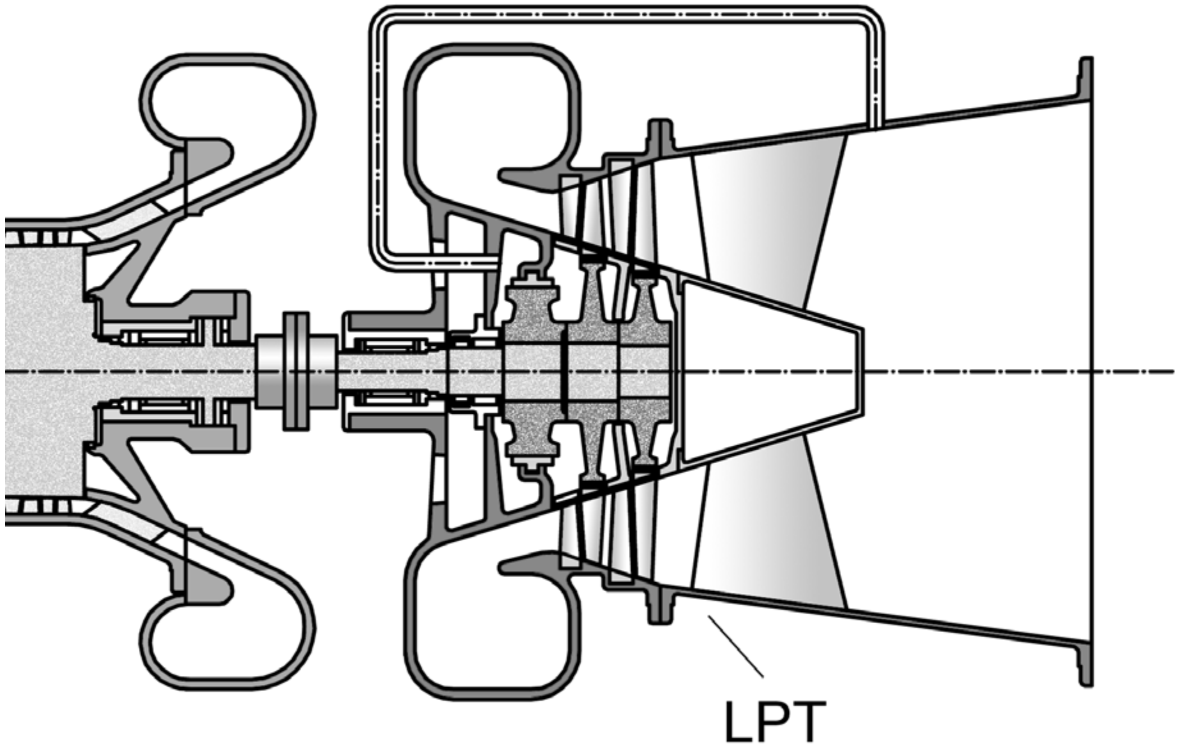
High Pressure Turbine



- Expansion of steam from 180 to 40 bar
- One radial and two axial stages to reduce shaft length
- Arranged between C3 compressor and HTT first stage
- 20 000 rpm

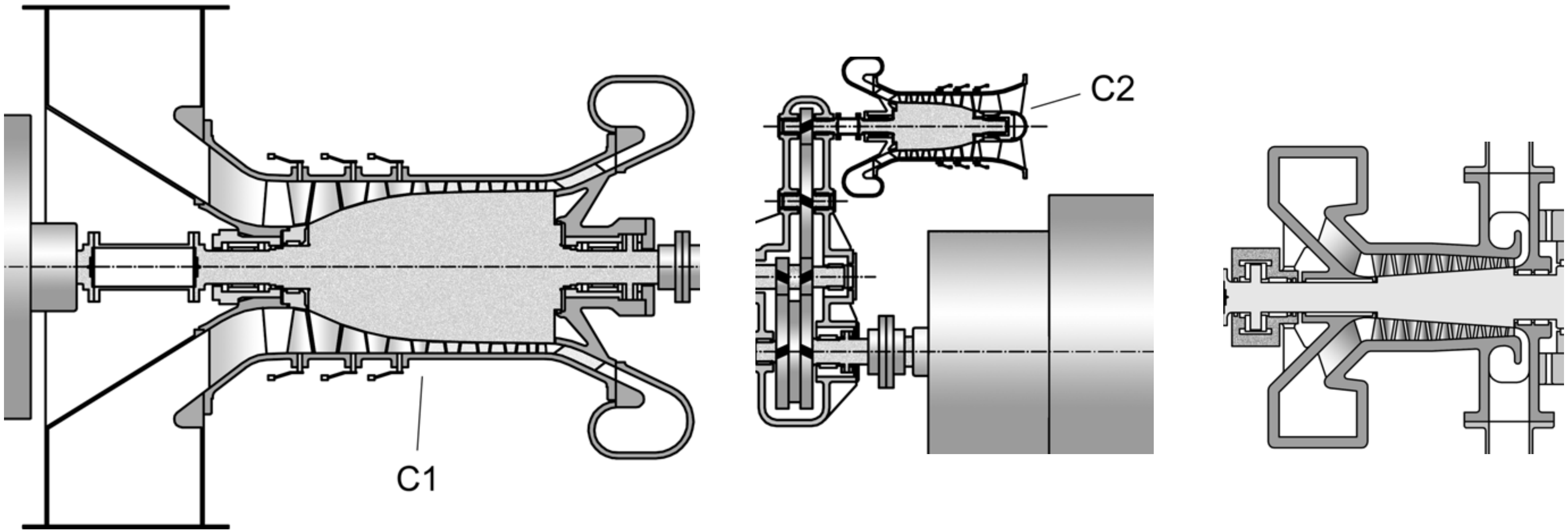
Low Pressure Turbine

- Conventional design
- Expansion of CO2/H2O mixture to condensation pressure (0.25 bar)
- Connection to C1 compressor
- 3 000 rpm



CO2 compressors C1, C2, C3

- Compression of CO_2 from 0.25 bar to 40 bar
- Extraction of CO_2 from combustion after C1 compressor
- Due to high volume change of CO_2 during compression three different rotational speeds (3 000, 12 000, 20 000) are necessary
- Due to low sonic speed of CO_2, C2 and C3 have an inlet tip Mach number of 1.3 - 1.4



Heat Recovery Steam Generator

- **Maximum temperature of 640 °C leads to high temperature alloys**
- **Layout with high temperature differences to reduce costs**
- **Problems due to CO_2 solubility in feed water in the low temperature region can occur (this can lead to corrosion)**

Conclusions

- **Presentation of the Graz Cycle as "closed gas turbine cycle " with CO_2 retention**
- **Thermodynamic layout promises efficiencies up to 64 % (57.5 % if expenses of O_2 supply are considered)**
- **Possible arrangement of turbomachines is presented which allows short flow paths in the hot sections**
- **Two sets of turbomachines**
1st set at 20 000 rpm
2nd set at 12 000/3 000 rpm
- **The work shows the feasibility of building a Graz Cycle power plant which allows full CO_2 retention only with the use of turbomachines**
- **The next step would be the erection of a demonstration plant through an international cooperation**