**Institute for
Thermal Turbomaschinery
and Machine Dynamics**

**Graz University of Technology
Erzherzog-Johann-University**

Design Details of a 600 MW Graz Cycle Thermal Power Plant for CO_2 Capture

Presentation at the
ASME Turbo Expo 2008
Berlin, Germany, June 9 - 13, 2008

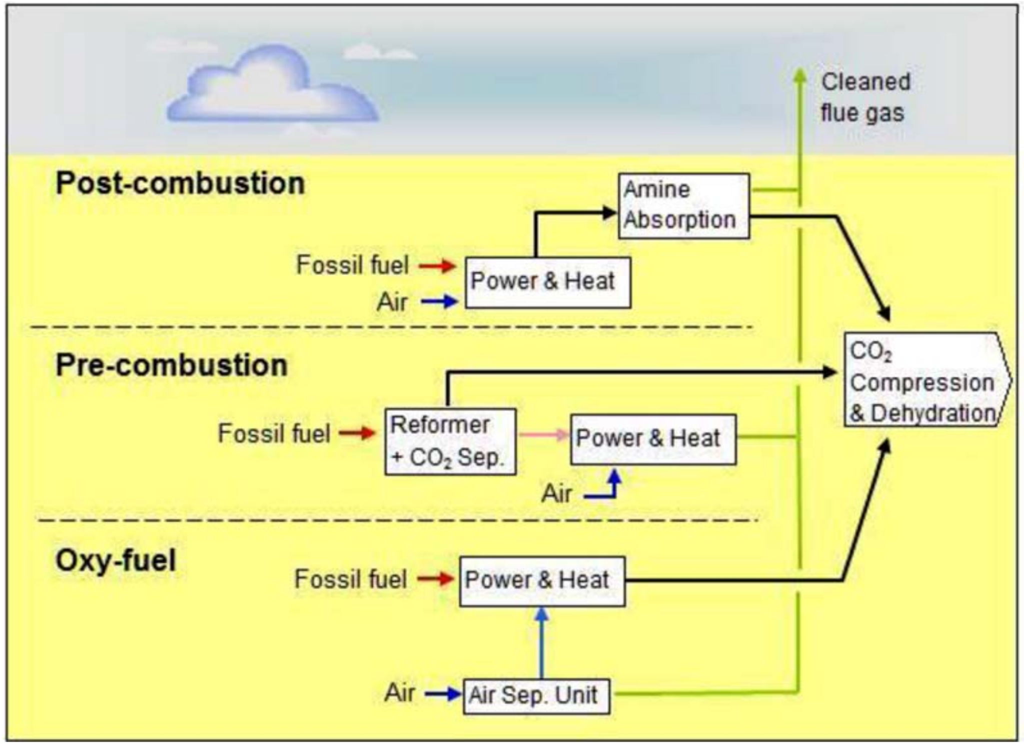
Herbert Jericha, Wolfgang Sanz, Emil Göttlich and Fritz Neumayer
Institute for Thermal Turbomachinery and Machine Dynamics
Graz University of Technology
Austria

Background - I

- Worldwide ever rising emissions of greenhouse gases to atmosphere ->
  global warming and environmental change
- Kyoto Protocol demands the reduction of greenhouse gases, mainly CO2
- In EU: strong pressure on utilities and companies to reduce CO2 emissions
- Carbon capture and storage (CCS) as short and mid term solution
- CCS can be done for natural gas and coal

Background - II (CCS Technologies)

- **Post-combustion:** CO2-Capture from exhaust gas (chemical absorbtion, membranes, …)
- **Pre-combustion:** Decarbonization of fossil fuel to produce pure hydrogen for power cycle (e.g. steam reforming of methane, …)
- **Oxy-fuel power generation:** Internal combustion with pure oxygen and CO2/H2O as working fluid enabling CO2 separation by condensation



Which technology has the best chances to dominate future power generation ?

Oxy-Fuel Cycles

- **Oxy-fuel cycles with internal combustion with pure oxygen are a very promising technology** (**Global Gas Turbine News 10/2005**)

\+ **CO2 can be easily separated by condensation from working fluid consisting of CO2 and H2O, no need for very penalizing scrubbing**

\+ **Very low NOx generation, NOx is not emitted**

\+ **Flexibility regarding fuel: high CO2 content natural gas, syngas from coal, biomass or refinery res. gasification**

\- **New equipment required**

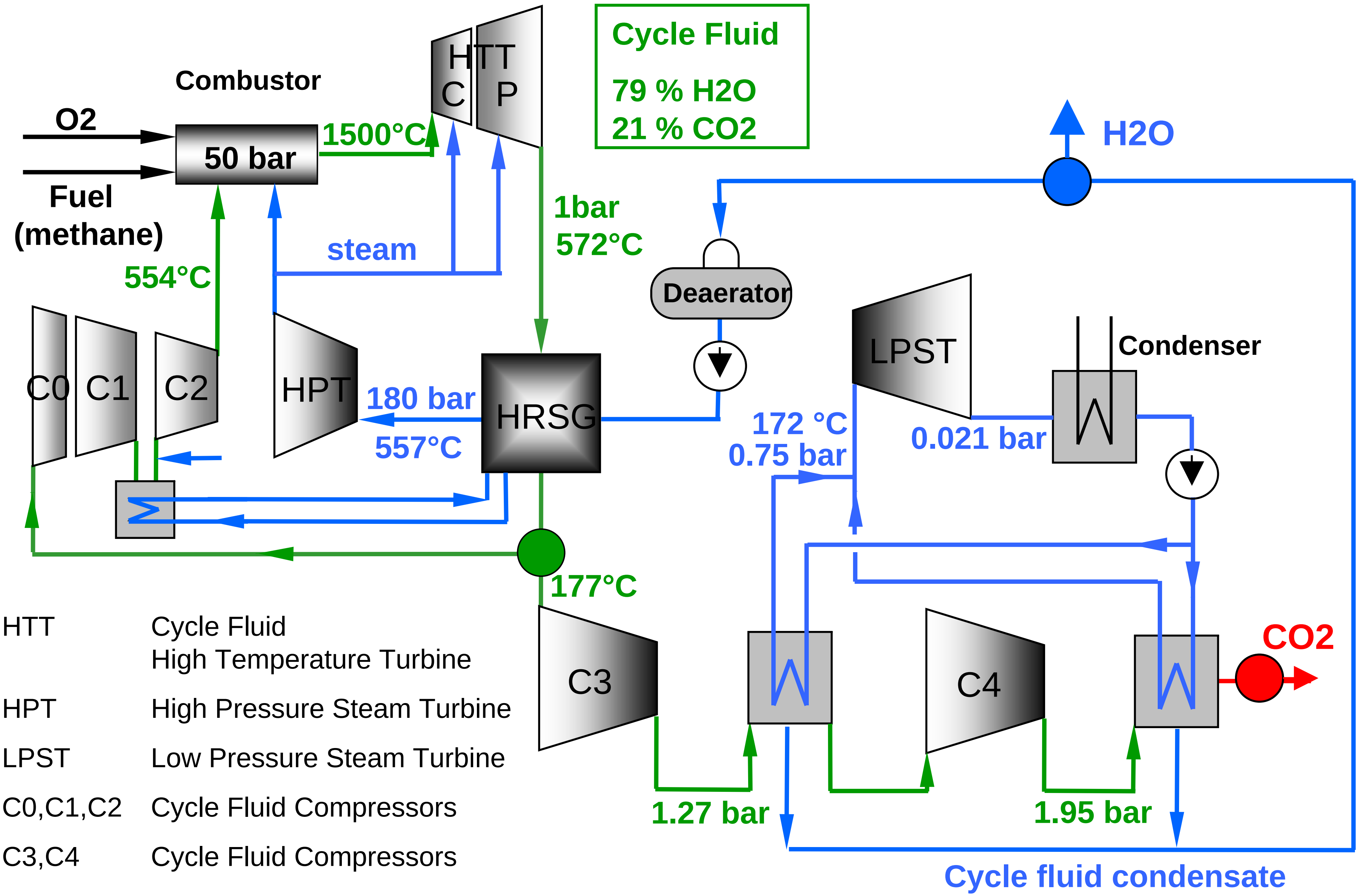
\- **Additional high costs of oxygen production**

\+ **These new cycles show higher efficiencies than current air-based combined cycles (Graz Cycle, Matiant cycle, Water cycle,...)**

Objective

- In 2003 design details for a 75 MW unit were presented at the ASME IGTI conference in Atlanta
- Power output raise to 400 MW was presented at ASME IGTI conference 2006 in Barcelona and at CIMAC conference 2007 in Vienna
- In continuation of these works a raise of power output to 600 MW is presented here and important design details are discussed.
- In order to achieve this goal combustor pressure and turbine inlet temperature are increased to values well acceptable in standard gas turbine development
- Additional pre-compressor stage allows to use the same compressors as for 400 MW

Cycle Scheme for 600 MW net output



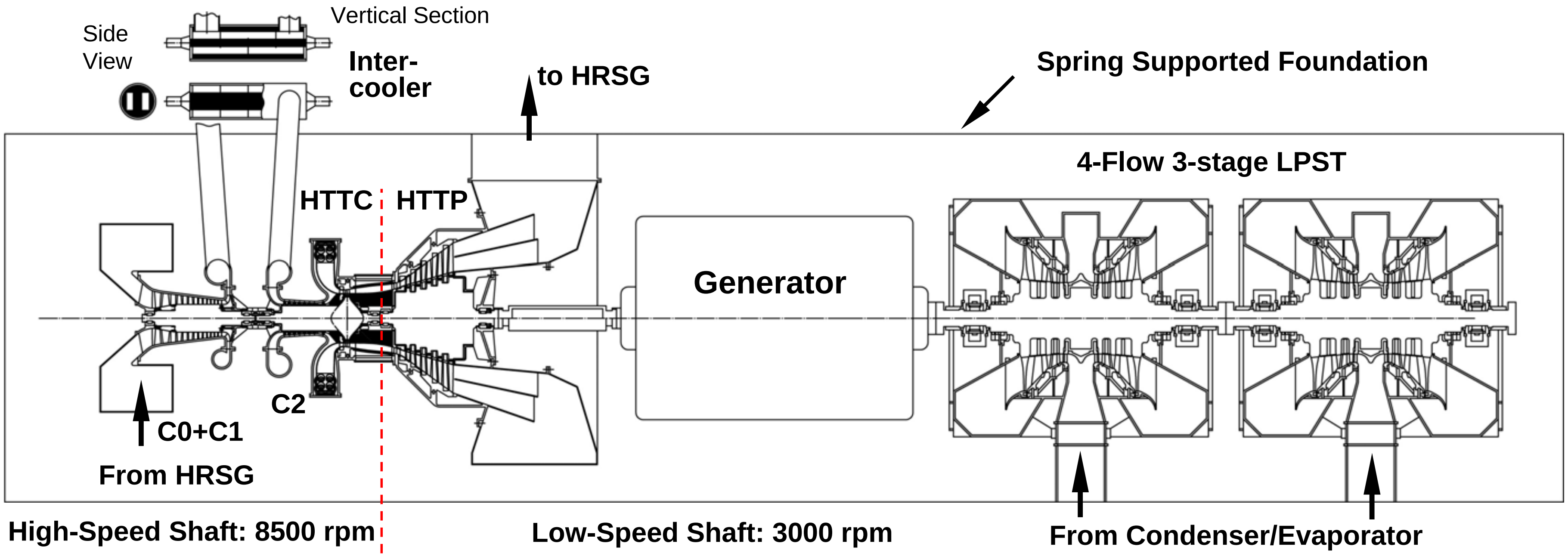
HTT	Cycle Fluid High Temperature Turbine
HPT	High Pressure Steam Turbine
LPST	Low Pressure Steam Turbine
C0,C1,C2	Cycle Fluid Compressors
C3,C4	Cycle Fluid Compressors
HRSG	Heat Recovery Steam Generator

Graz Cycle Power Balance

	400 MW	600 MW		400 MW	600 MW
HTT power [MW]	617.9	908	Net shaft power [MW] w/o mechanical losses	504.7	746
HPT power [MW]	49.9	62	Total heat input Q_{zu} [MW]	758.6	1100
LPST power [MW]	71.6	101	**Thermal cycle efficiency [%]**	**66.52**	**67.6**
Total turbine power P_T [MW]	**739.4**	**1071**	Electrical power output [MW] incl. mechanical, electrical & auxiliary loss	490.7	724.6
C0 power [MW]	-	8.8	**Net electrical cycle efficiency [%]**	**64.68**	**65.71**
C1 power [MW]	131.1	178	O_2 generation & compression P_{O2} [MW]	74.7	109
C2 power [MW]	82.6	108	**Efficiency considering O_2 supply [%]**	**54.83**	**55.83**
C3+C4 power [MW]	15.5	23	CO_2 compression to 100 bar P_{CO2} [MW]	13.0	18.6
Pump power [MW]	5.5	7.2	**Net power output [MW]**	**403.0**	**597**
Total compression power P_C [MW]	**234.7**	**325**	**Net efficiency [%]**	**53.12**	**54.14**

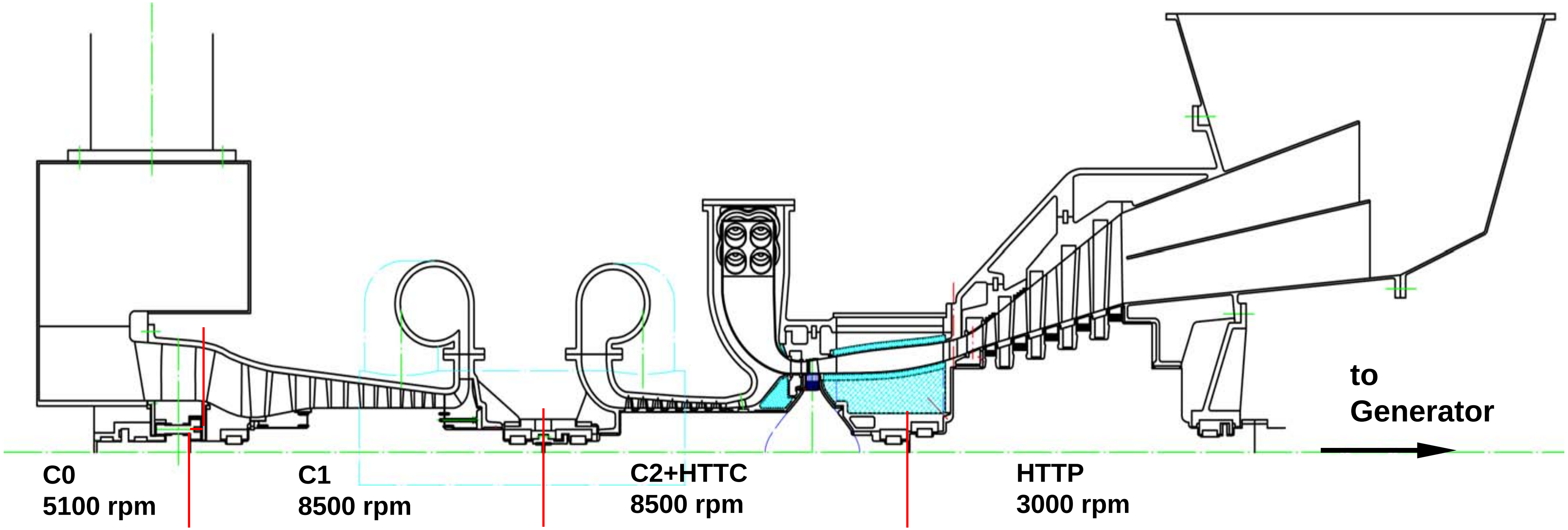
Arrangement of Main Turbo Shaft - 725 MW

- Main gas turbine components on two shafts for 600 MW net output
- Compression shaft of 8500 rpm: cycle compressors C0, C1 and C2, driven by first part of HTT, the compressor turbine HTTC
- Power shaft of 3000/3600 rpm: power turbine HTTP as second part of HTT drives the generator
  Four-flow LPST at the opposite side of the generator
- Shafts on same spring foundation
  Intercooler between C1 and C2 on fixed foundation connected to HRSG



Main Turbo Shaft

- **Main gas turbine components on two shafts for 600 MW net output**
- **Higher power obtained by design improvements (higher compression ratio, higher peak temperature)**

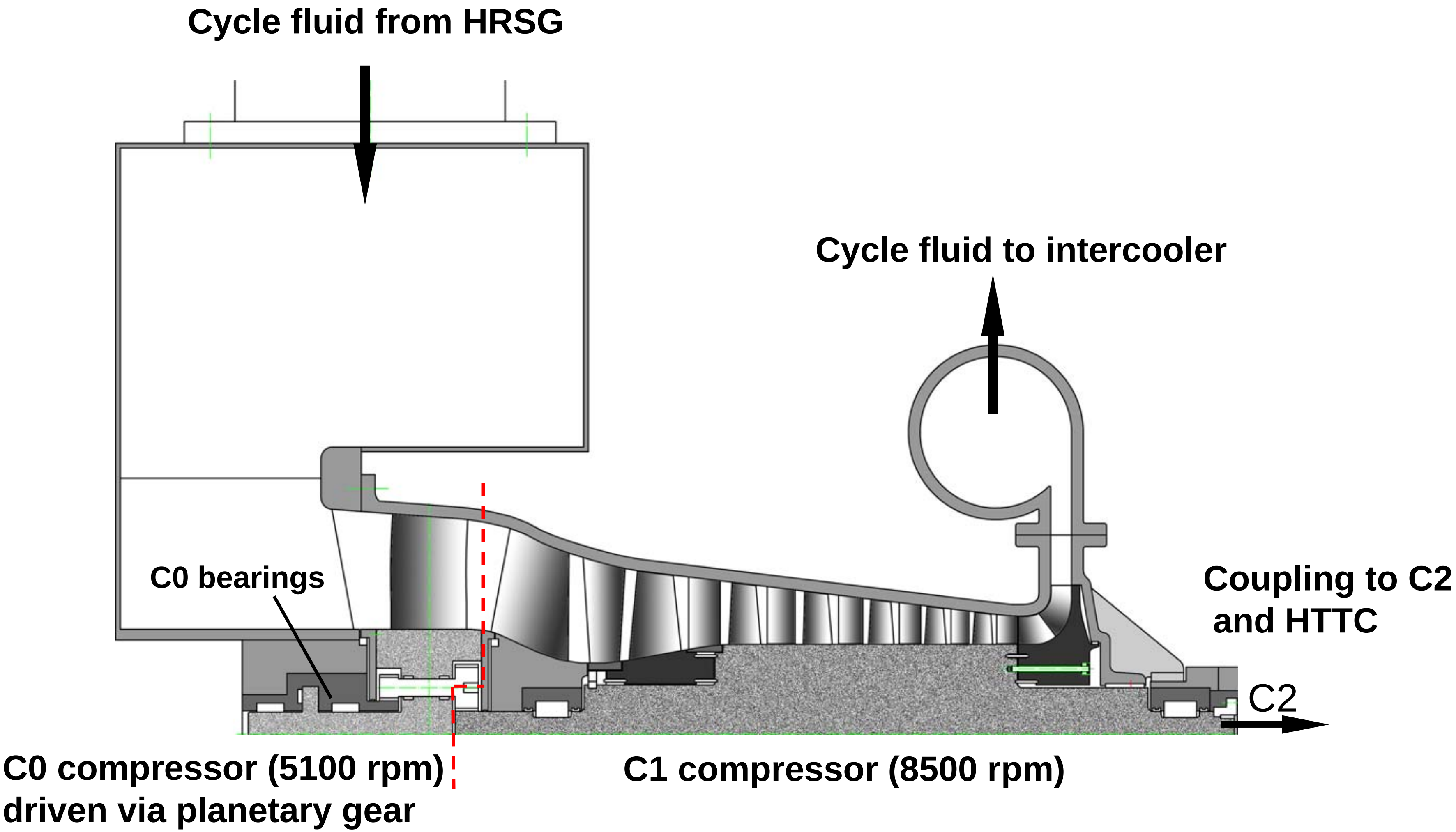


Single stage transonic turbine drives compressor shaft (C0, C1 and C2)

Power turbine HTTP –
5 subsonic stages at 50 Hz
4 subsonic stages at 60 Hz

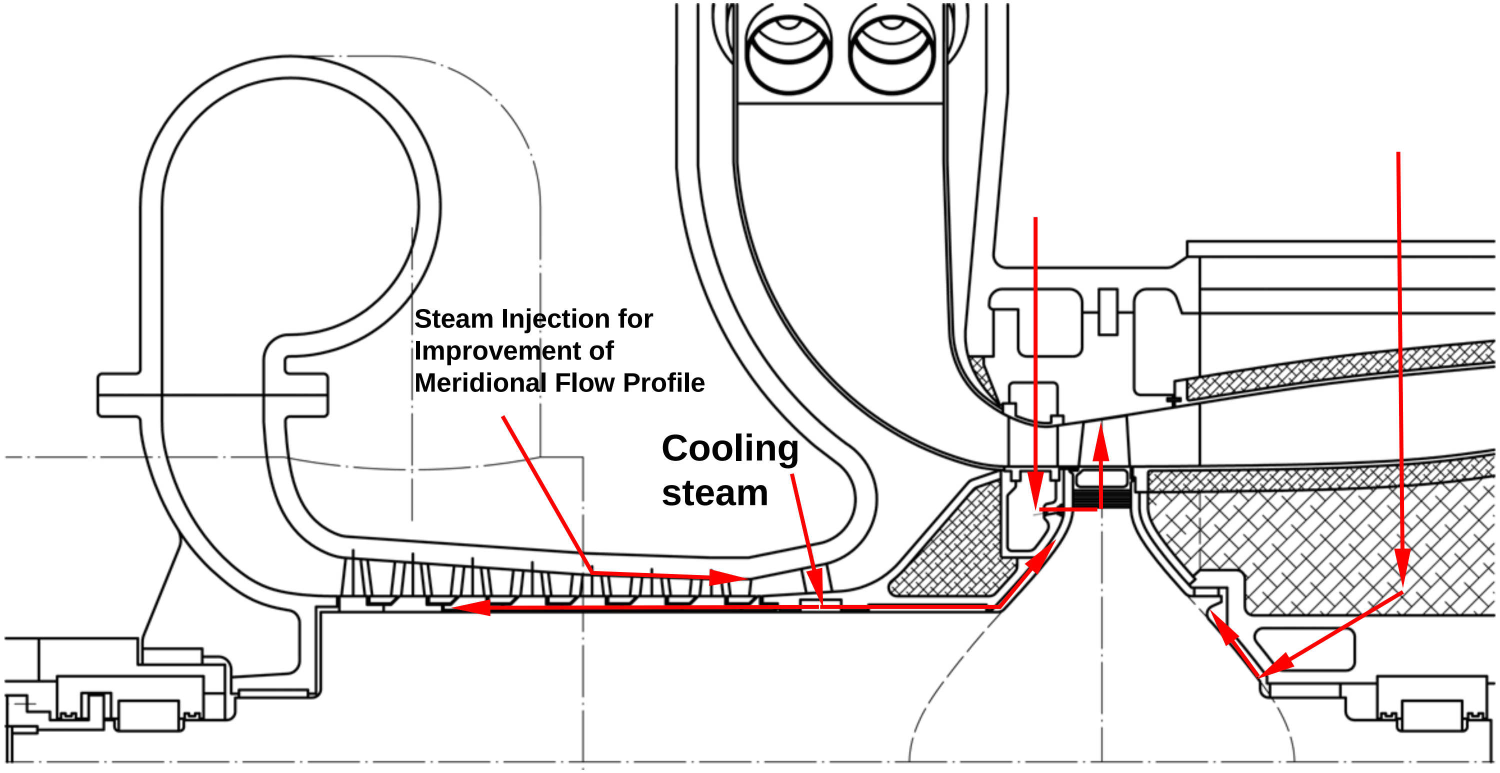
C0 and C1 compressor details

- **Pre-arranged loading compressor C0 serves for higher mass flow to combustion chamber keeping volume flow to C1 equal to previous layout**
- **Speed change allows to keep tip Mach number at 1.3**

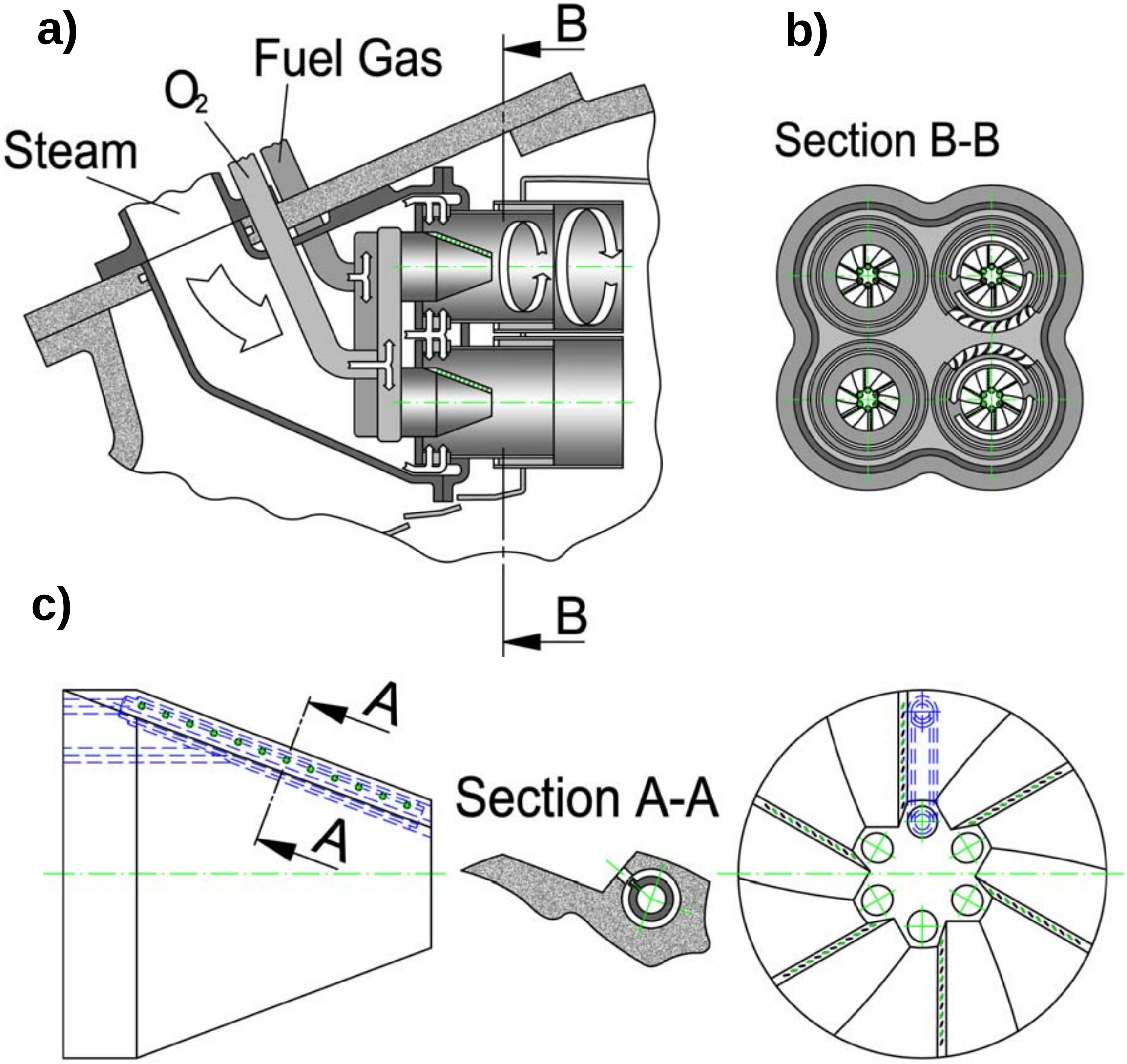


Steam Cooling Details of HTTC and C2

- HTTC and C2 on common shaft with a disk of constant stress
- Disk is cooled on both sides with cooling steam of 300°C
- Cooling steam on right-hand-side: balancing of axial thrust
- C2 rotor: cooling to avoid creep



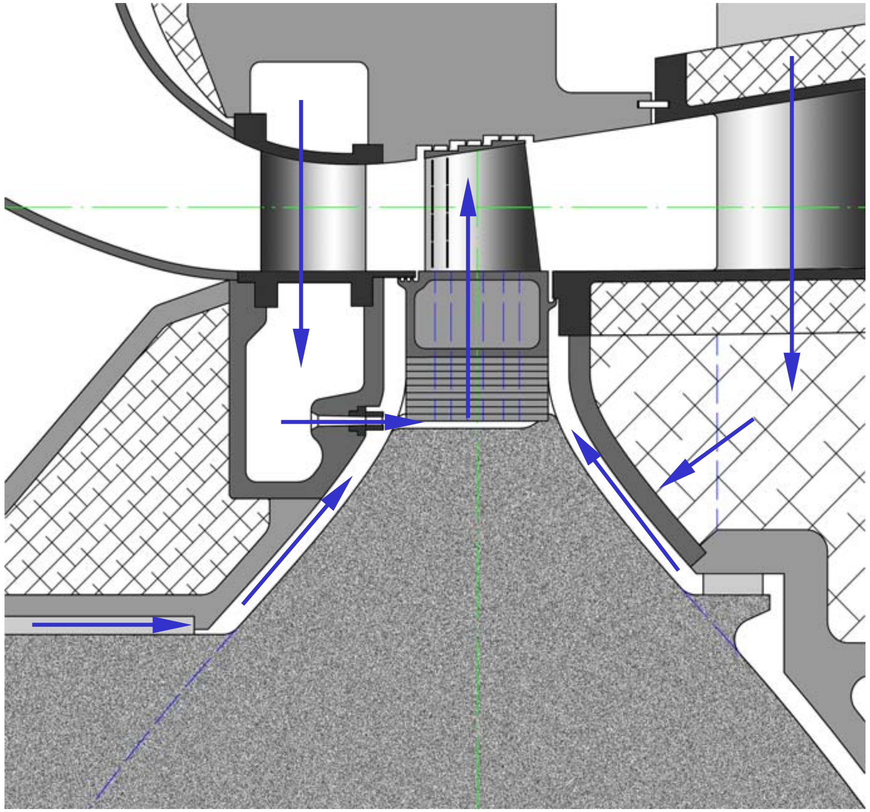
Combustion Chamber

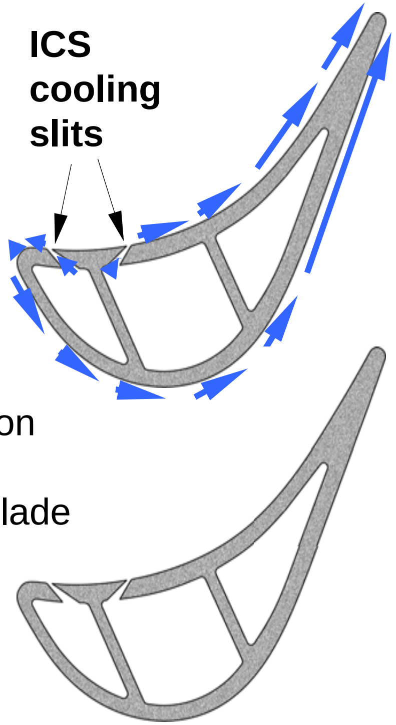


- Stoichiometric combustion of fossil fuel and O2 at 50 bar
- Combustor exit temperature: 1500 °C
- Oxidizer is not cooling medium, thus risk of incomplete combustion. So fuel and O2 inflow have to be kept in close contact in steam-driven burner vortex
- In inner cylindrical shell fuel and O2 combustion takes place partly cooled by inner steam vortex flow
- Outer cylindrical shell conducts cycle fluid in counter-rotating vortex to locally defined vortex break-down
- Annular flame casing with 6 quadruples of burner tubes
- Cooling of annular flame cage by recompressed working fluid serving for proper mixing and guiding to first nozzles

Transonic Stage Steam Cooling

- Cooling steam entry through hollow nozzles
- Collection in inner annular chamber
- Jet in partly tangential direction to provide optimal inflow into blade root
- Radial outflow of cooling steam through fir-tree root into hollow blade in innovative cooling system (ICS)



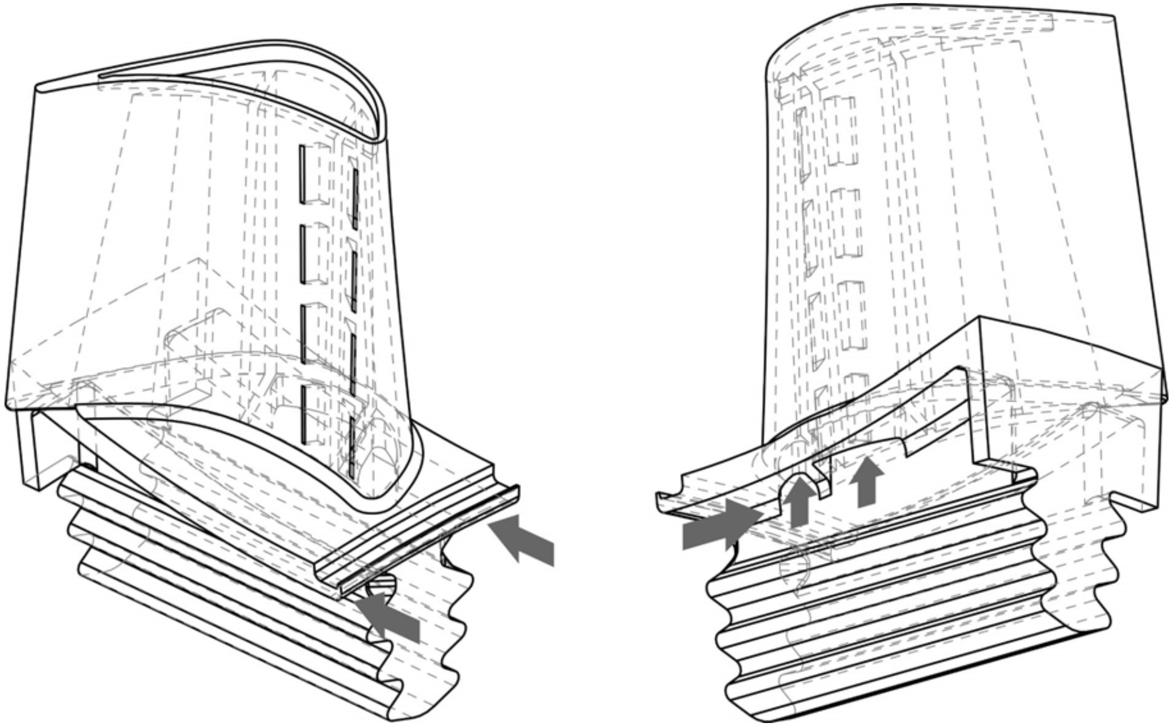


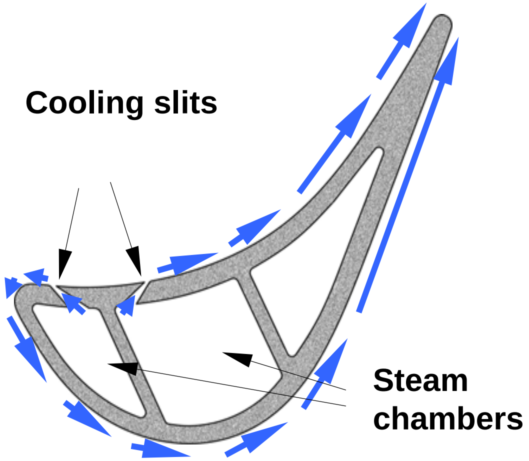
Exit of under-expanded transonic steam flow covering whole blade surface by a coherent layer of steam

ICS cooling slits

High-reaction high-flow-efficiency blade channel

3D cooling arrangement of HTTC stage (previous work)

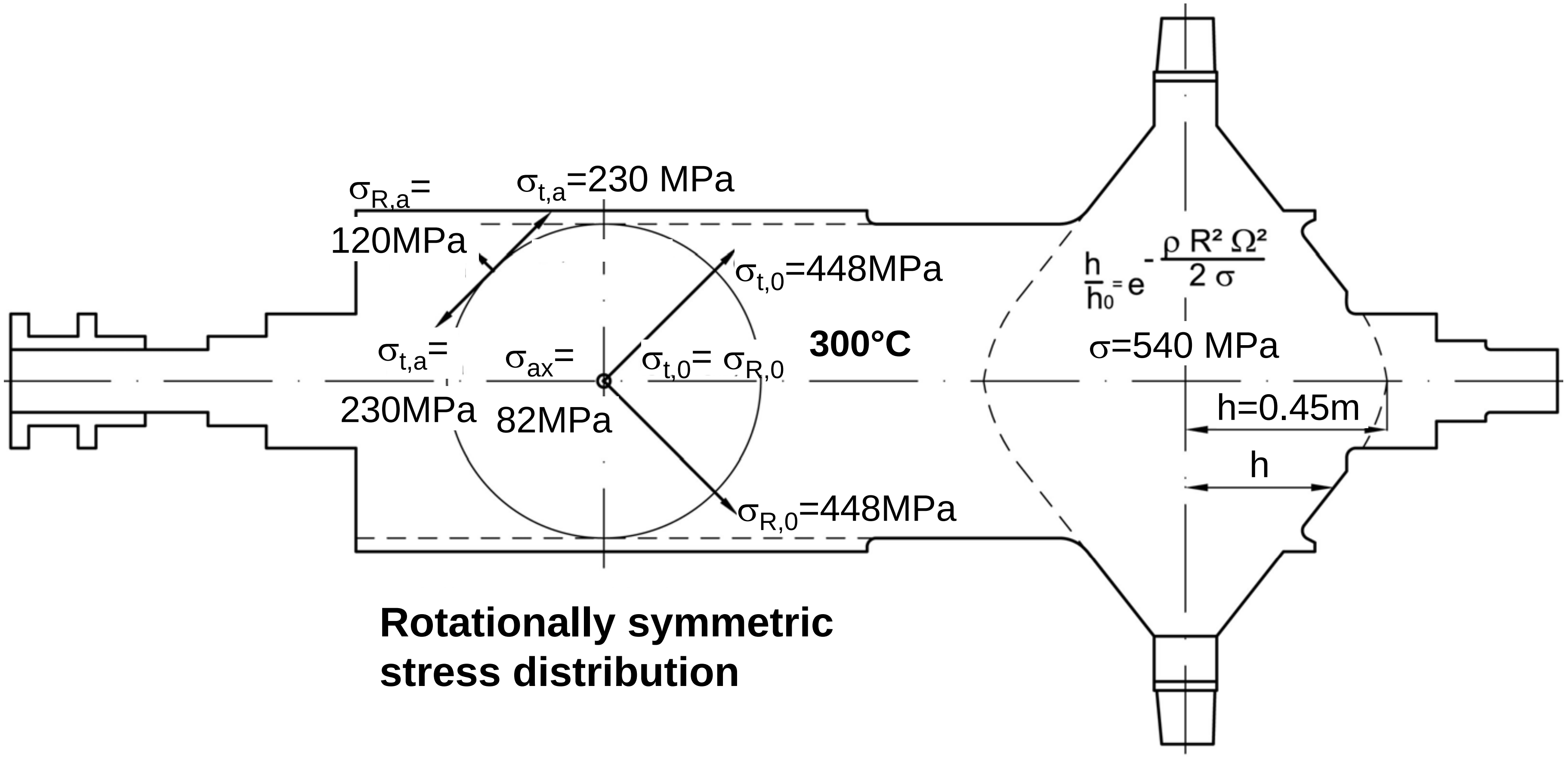




Blade with ICS steam cooling as proposed for 75 MW Graz Cycle presented at ASME Turbo Expo Atlanta 2003

Stress of C2-HTTC shaft

- **Analytic solutions for three-dimensional stress**
- **Rotor cooled to 300°C**



Rotationally symmetric stress distribution

Conclusions

- **Graz Cycle is an oxy-fuel power cycle of highest efficiency for CO2 retention**
- **Raise of system power from 400 MW to 600 MW is presented**
- **This was made possible by a 50 bar combustion chamber with 1500°C peak temperature, increasing plant efficiency to 54.1 %**
- **Additional stage ahead of C1 working fluid compressor allows to maintain the inlet volume flow, so that the same design of the C1 and C2 compressors can be used for the 400 and 600 MW plant.**
- **Detailed deliberations on cooling, material selection, stresses and combustion chamber design are given**
- **We hope that our work will help industry to achieve a successful result in manufacture and operation in the short time limits indicated by European ZEP initiative and the warnings of Princeton University (National Geographic, Sept. 2007)**