ERCOFTAC Spring Festival 2011

Piotr Lampart

New IMP PAN research - renewable energy technologies

Gdańsk, 12 May 2011

SAMPLE IMP PAN / BKEE PROJECTS

1 **Model agro-energy complexes in distributed coegeneration of heat and power – Key Project of POIG**
Head – Prof. J. Kiciński

2 **Advanced technologies for energy production. Task 4. Elaboration of integrated technologies for the production of fuels and energy from biomass, agricultural waste and other waste materials – Strategic Programme of NCBiR**
Head – Prof. J. Kiciński

3 **The Baltic Sea Bioenergy Promotion Programme**
INTERREG IV C

4 **Border-free energy care – NORWEGIAN FINANSE MECHANISM**

5 **Evnironmet-friendly energy development of communes (gminas) – NORWEGIAN FINANSE MECHANISM**

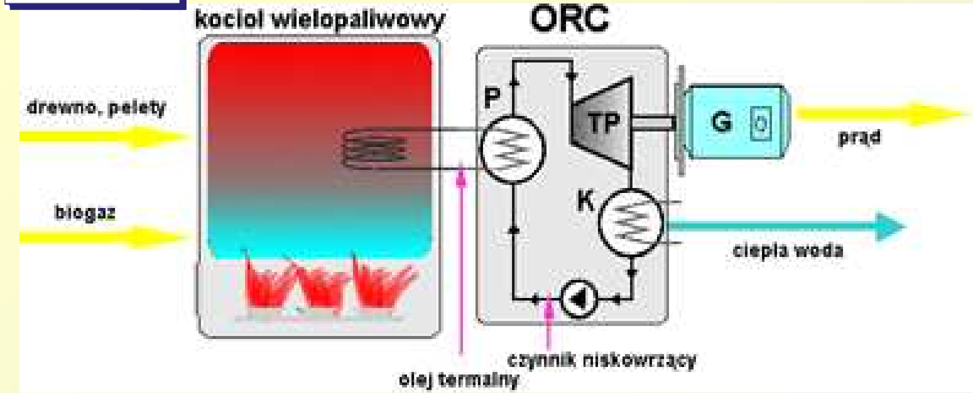
Aims of the Strategic Programme

- **Elaboration of technologies for the production of biofuels integrated with cogeneration of electric and heat.**
- **Elaboration of documentation of a series of distributed energy systems**
- **Preparation of demo instalations ready for implementations in energy industry**

Main research areas

- Cogeneration of electric energy and heat from biomass/biogas
- Micro-biogas stations
- High-temperature gasification of biomass and waste
- Biomass fermentation to biogas
- Biorafinery
- Fuel cells and cogeneration on SOFC
- Pufirication of biogas and syngas
- Microgrids
- Small wind and water turbines, hybrid RES

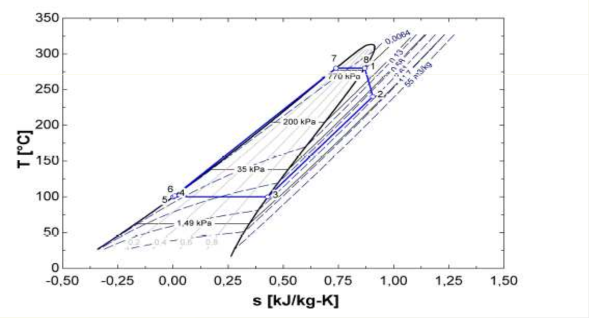
Demo instalation – ORC cogeneration complex (0.15MWe)



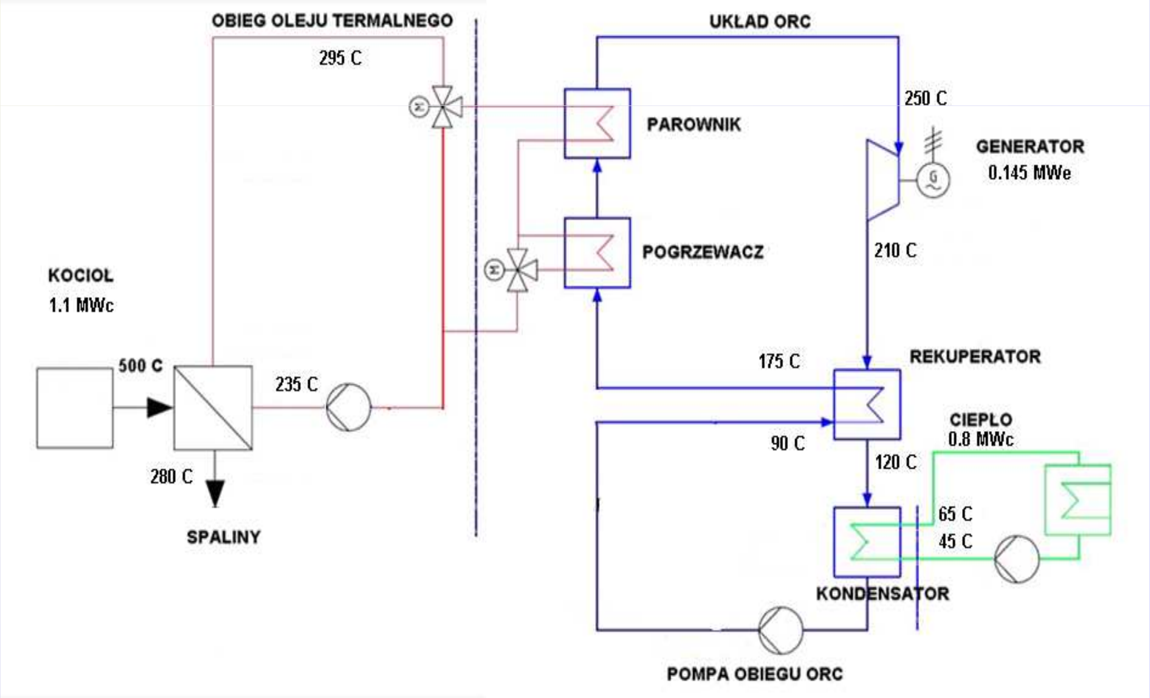
Thermal oil loop 295°C/235°C

Silica oil loop:

- **turbine - 7.6 bar/250°C - 0.14 bar/210°C**
- **recuperator – vapour 210/120°C,**
  liquid 90/175°C
- **preheater – 175°C/250°C**
- **evaporator - 250°C**
- **condenser - 90°C**
- **Hot water (summer) 65°C/45°C,**

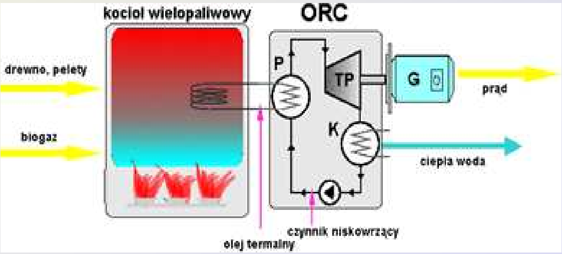


Medium – silica oil

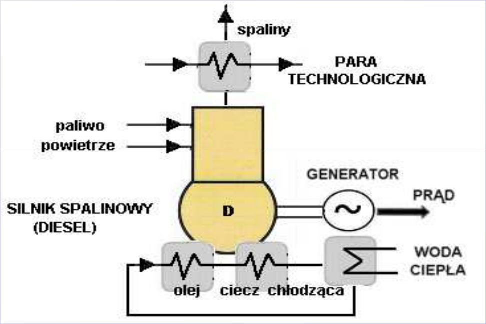


Heat station upgrade

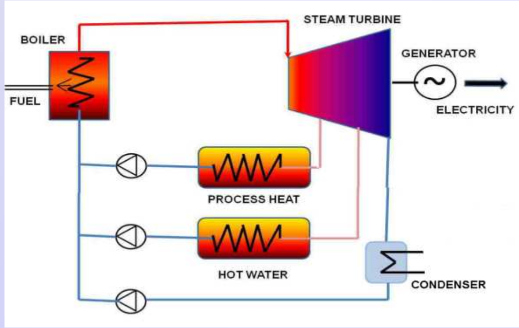
- Closing 3 coal boilers



- Instalation of a biomass fired ORC system (0.8MWth, 0.15MWe)

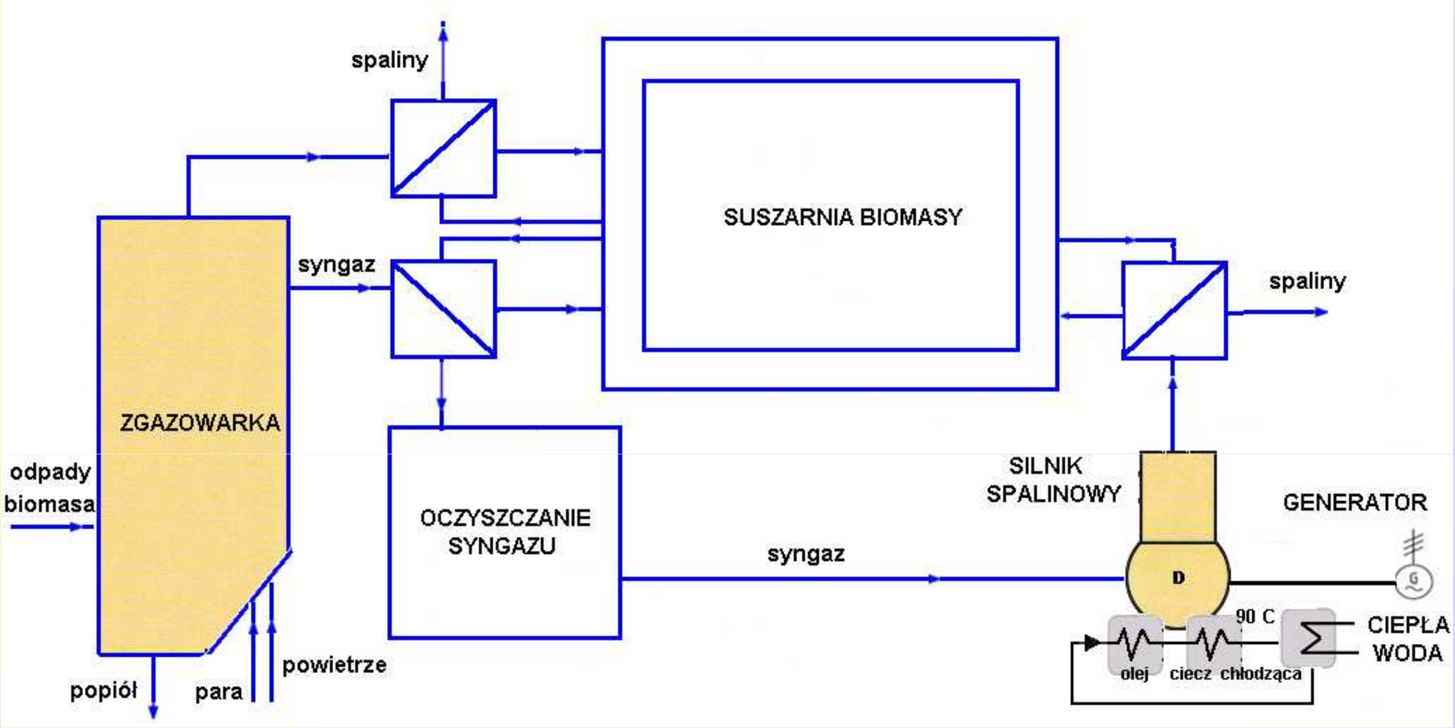


- Installation of a natural gas fired cogeneration system based on two piston engines (3.5MWth, 3.2MWe)



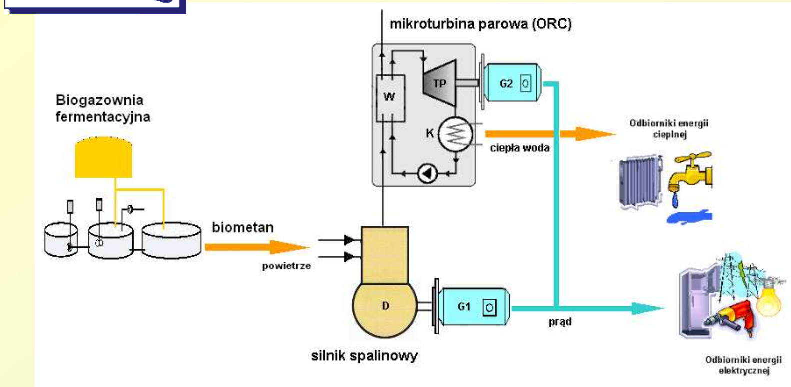
- Installation of a biomass fired steam cogeneration system (5.2MWth, 2.7 MWe)
- Modernisation of 1 coal boiler (10MWt)

Demo instalation -
cogeneration system for a biomass processing factory



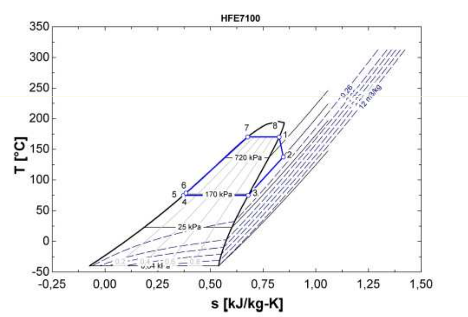
- **Gas reactor,**
- **Syngas purification system,**
- **Piston combustion engine with generator 0.5MW,**
- **Heat recovery system for biomass drying.**

Demo installation - cogeneration gas / ORC cycle (0.6MWe)

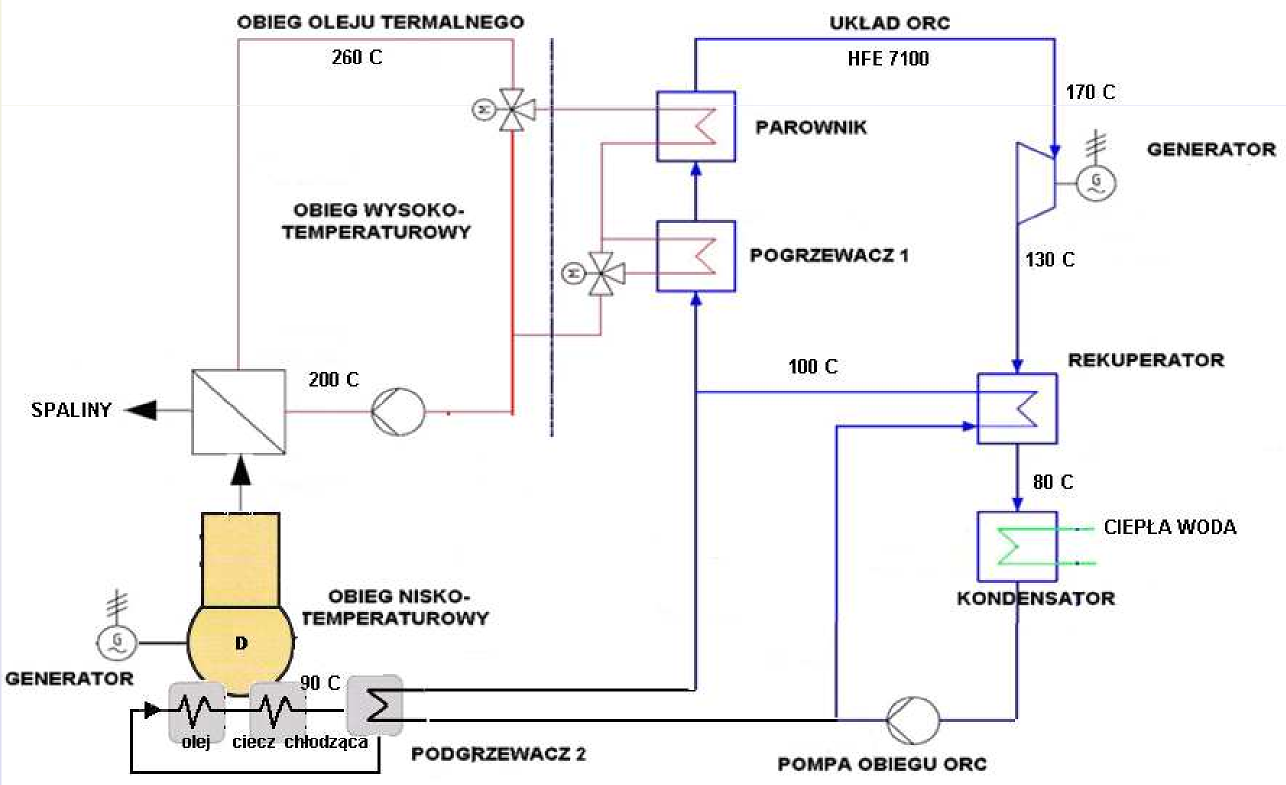


Thermal oil loop - 260^{o}C/200^{o}C

Medium loop (HFE 7100):
- turbine - 15 bar/170^{o}C - 2 bar/130^{o}C
- recuperator – vapour 130/80^{o}C, liquid 70/100^{o}C
- preheater 1 – 90^{o}C/170^{o}C
- preheater 2 – 70^{o}C/85^{o}C
- evaporator - 170^{o}C
- condenser - 80^{o}C
- Hot water (summer) 65^{o}C/45^{o}C,



Medium – HFE 7100



COGENERATION – specific research topics:

- **Theoretical, numerical and experimental investigations of combustion of low-caloric gases in piston engines and gas turbines**

- **Development of supply and ignition control systems for cogeneration engines fired by low caloric gases**

- **Theoretical, numerical and experimental investigation of poligeneration ORC cycles**

- **Investigation of thermodynamics properties of ORC fluids**

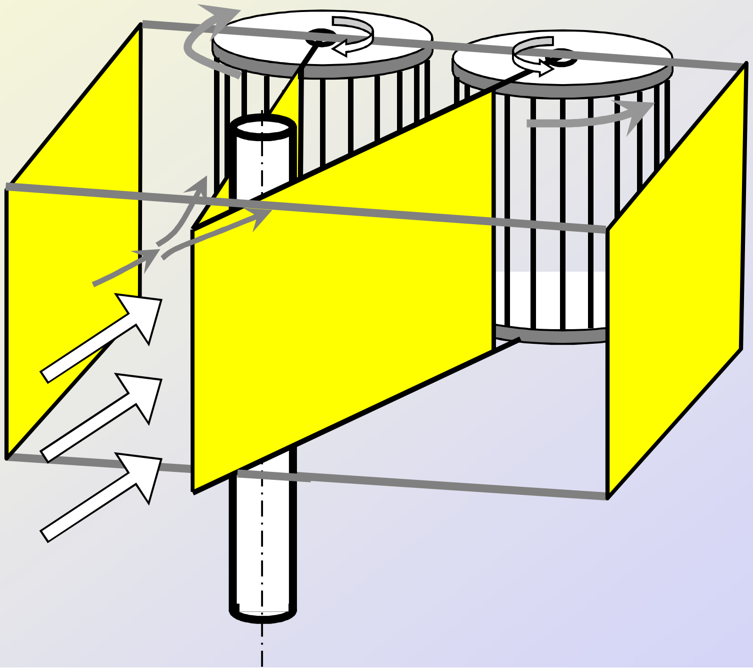
- **Investigation of aerodynamics and dynamics of micro- and mini-scale high-rotation turbogenerators**

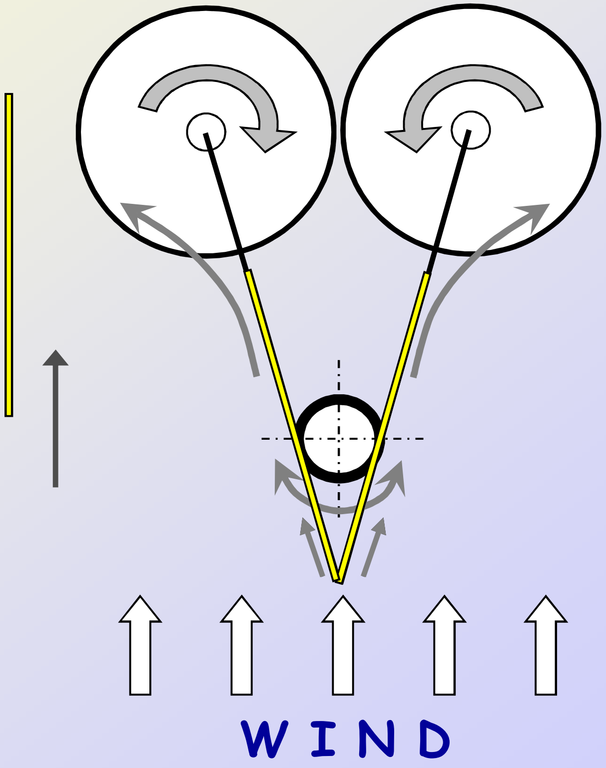
- **Investigation of cogeneration cycles based on recovery heat**

Small wind turbines at IMPPAN

Source: P. Doerffer

- Main interest 1 - 3 kW
- Customer tailored 10 – 15 kW



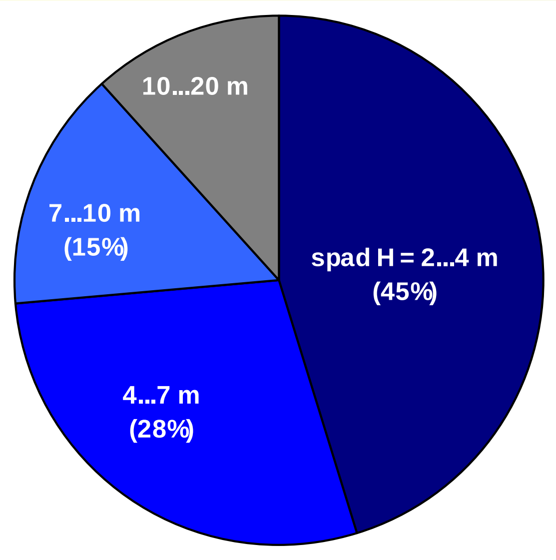


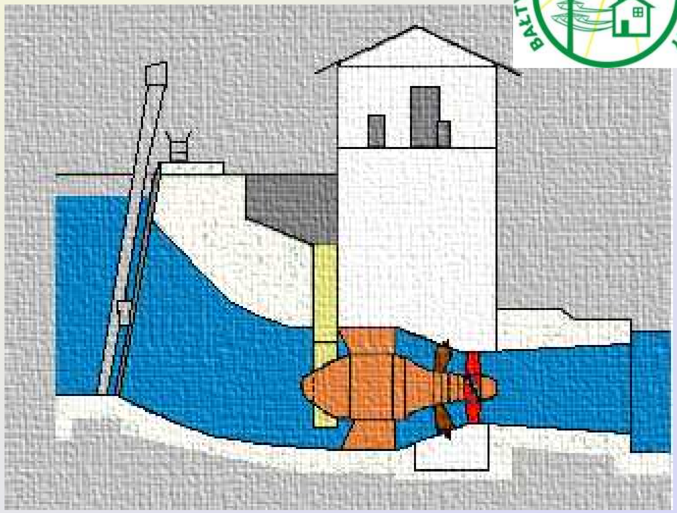
- **Vertical axis**
- **Counter-rotating drums**
- **Upwind elements covered.**

Micro hydro power: Low-head turbines

Why small hydro power should be developed?

Head structure in Poland - almost 50% are low-head objects, not used

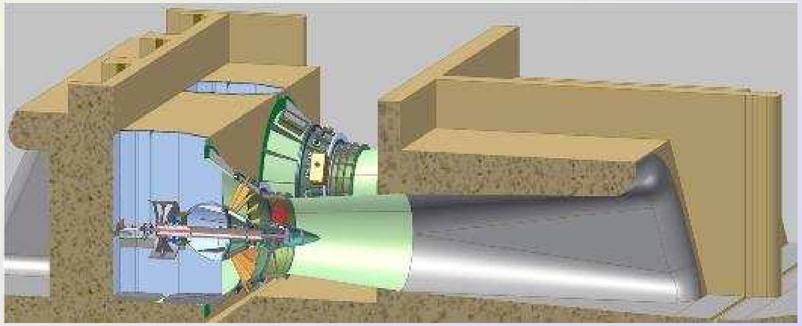




Source: A. Adamkowski

Innovation

- New blading systems of high a rotation coefficient,
- Control system for adjustable rotational velocity,
- New design methods,
- Optimisation of usage of water resources.

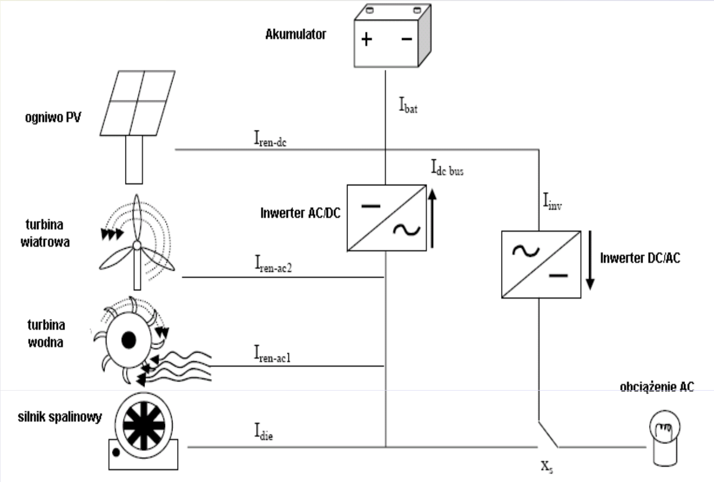


Low-head hydro turbine parameters:

• Head:	**$H = (1.5 – 4)$ m sł. wody**
• Flow:	**$Q = (0.3 – 12)\ m^3/s$**
• Power:	**$P_e = (10 – 350)$ kW**
• Expected efficiency:	**$\eta = (75 – 85)\%$**
• Rotation coefficient:	**$n_{SQ} = (250\text{-}280)$**

Hybrid RES

Energy production systems that draw on two or more energy sources

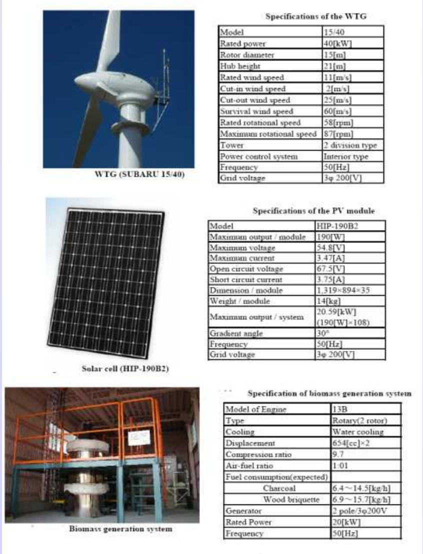


Good points:

- Overcome shortages of single source,
- Guarantee continuous supply,
- Guarantee less fuel consumption and emissions,
- HYRES promote RES.

Examples:

- wind turbine / PV / battery,
- wind turbine / compressor / compressed air tank / gas turbine,
- wind turbine / PV / diesel engine / battery,
- PV / PEM,
- wind farm / hydro pumped-storage,
- spark engine / electric engine,
- solar panels / ground heat store / heat pump / air-conditioning,
- solar panels / biomass boiler.



WTG (SUBARU 15/40)

Specifications of the WTG

Model	15/40
Rated power	40[kW]
Rotor diameter	15[m]
Hub height	21[m]
Rated wind speed	11[m/s]
Cut-in wind speed	2[m/s]
Cut-out wind speed	25[m/s]
Survival wind speed	60[m/s]
Rated rotational speed	58[rpm]
Maximum rotational speed	87[rpm]
Tower	2 division type
Power control system	Interior type
Frequency	50[Hz]
Grid voltage	3φ 200[V]

Solar cell (HIP-190B2)

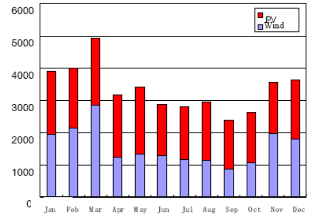
Specifications of the PV module

Model	HIP-190B2
Maximum output / module	190[W]
Maximum voltage	54.8[V]
Maximum current	3.47[A]
Open circuit voltage	67.5[V]
Short circuit current	3.75[A]
Dimension / module	1,319×894×35
Weight / module	14[kg]
Maximum output / system	20.59[kW] (190[W]×108)
Gradient angle	30°
Frequency	50[Hz]
Grid voltage	3φ 200[V]

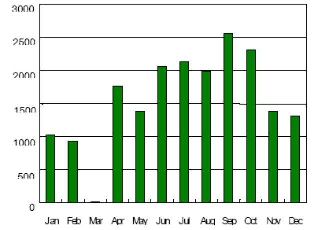
Biomass generation system

Specification of biomass generation system

Model of Engine	13B
Type	Rotary(2 rotor)
Cooling	Water cooling
Displacement	654[cc]×2
Compression ratio	9.7
Air-fuel ratio	1:01
Fuel consumption(expected)	
Charcoal	6.4～14.5[kg/h]
Wood briquette	6.9～15.7[kg/h]
Generator	2 pole/3φ200V
Rated Power	20[kW]
Frequency	50[Hz]



Expected energy production of WTG and PV



Necessary energy production of biomass generation system

Source: Ashikaga Inst.Tech.

Partial admission turbines

- Partial admission increases internal efficiency of small turbines

- Partial admission introduces strong circumferential non-symmetry of flow parameters in the control stage and is a cause of additional unsteady loads of the rotor blades.

- Due to a rapid change of load while entering and leaving the arc of admission, the rotor blades and also blade-fit regions experience higher unsteady mechanical stresses and are more vulnerable to failure.

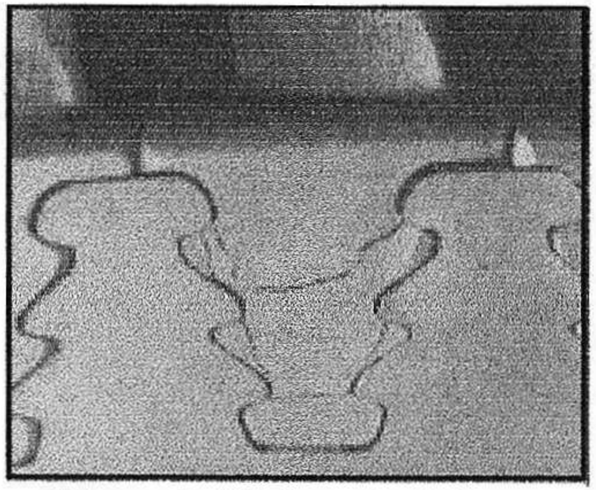
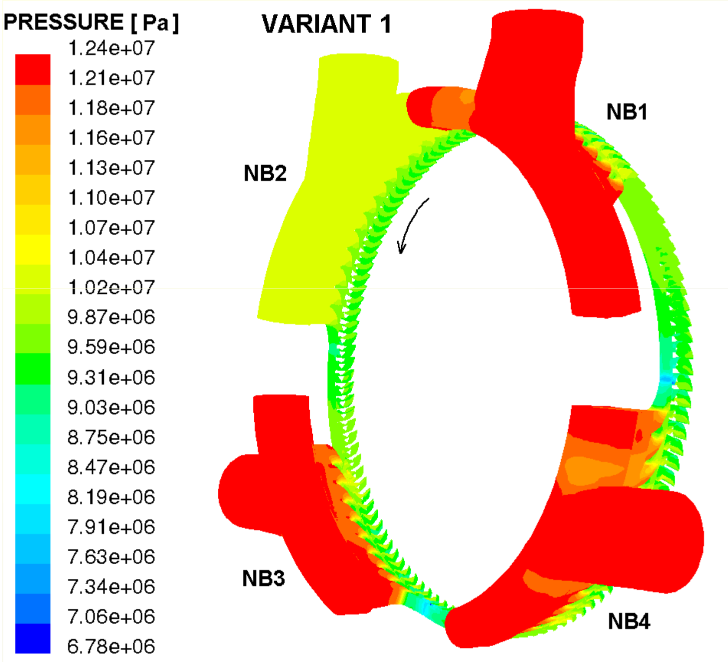


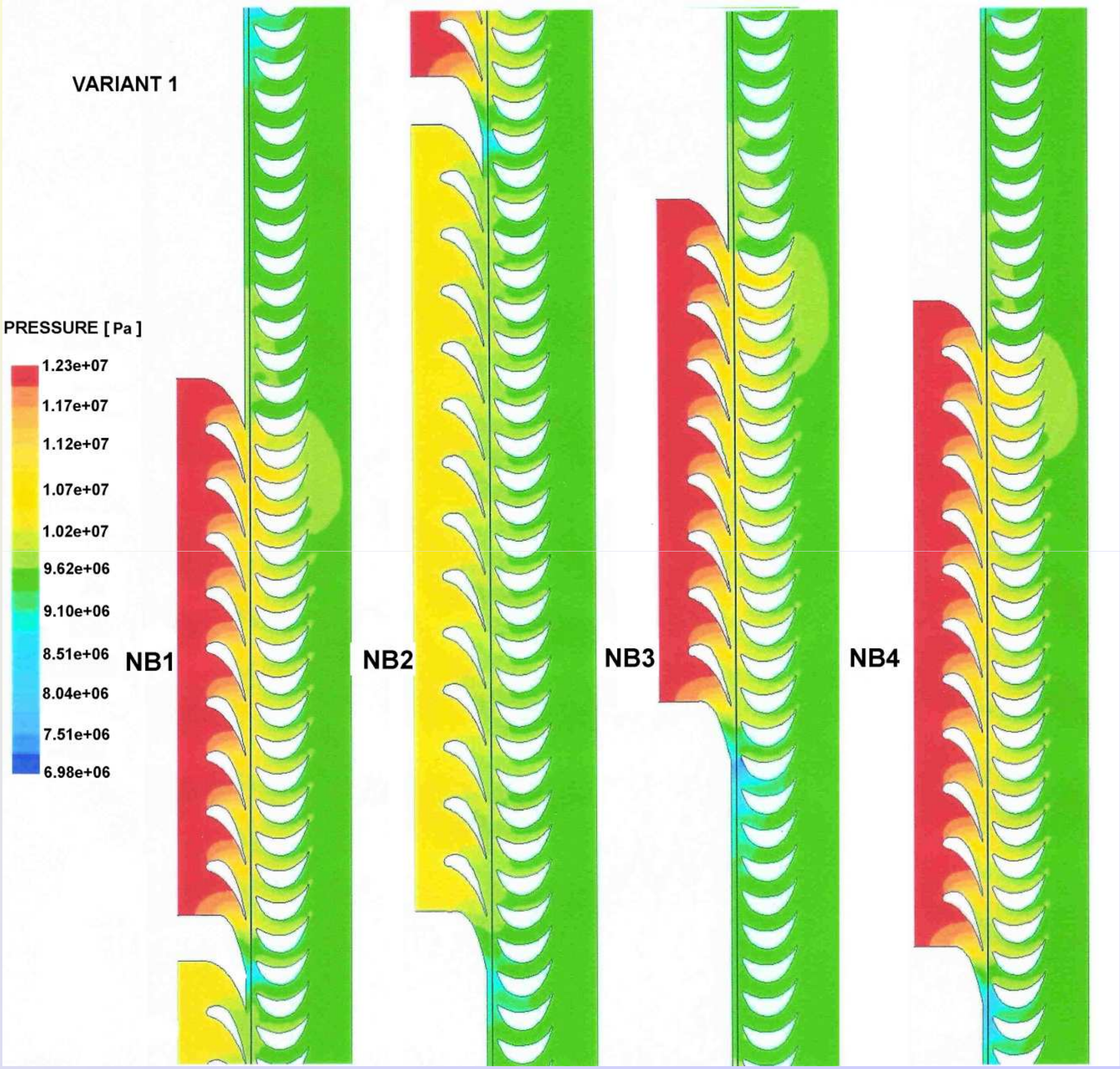
Figure 1. High cycle fatigue cracking in the blade-fit area (courtesy of EPRI)

➲ The operation of the partial admission stage gives also rise to excessive low-frequency excitations that may be dangerous for the dynamics of the system of rotor shaft, bearings and supports.

Source: P. Lampart, M. Szymaniak

Partial admission turbines

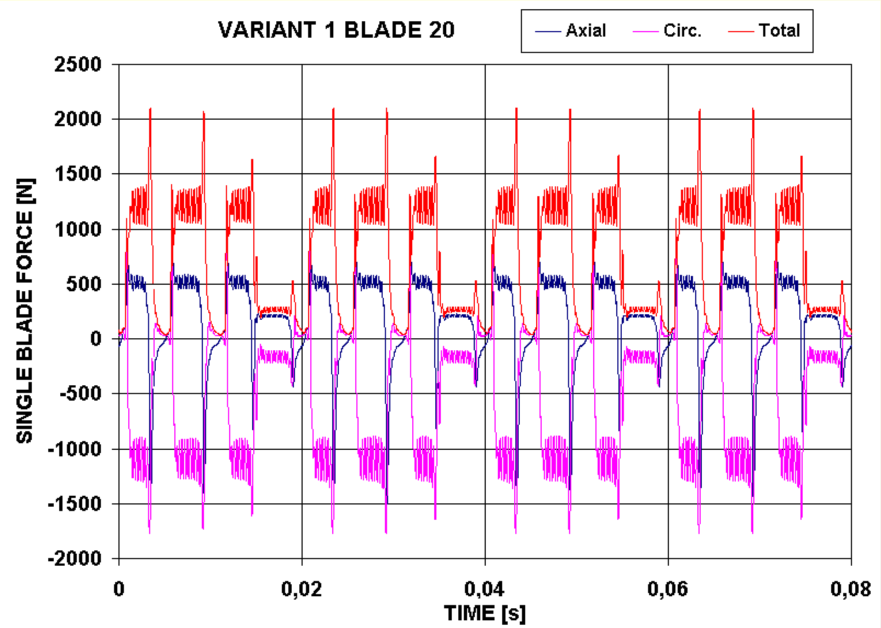


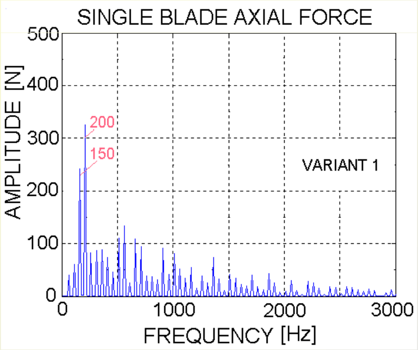


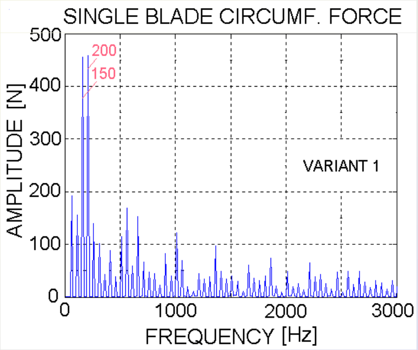
Instantaneous isolines of static pressure
in the control stage cascades

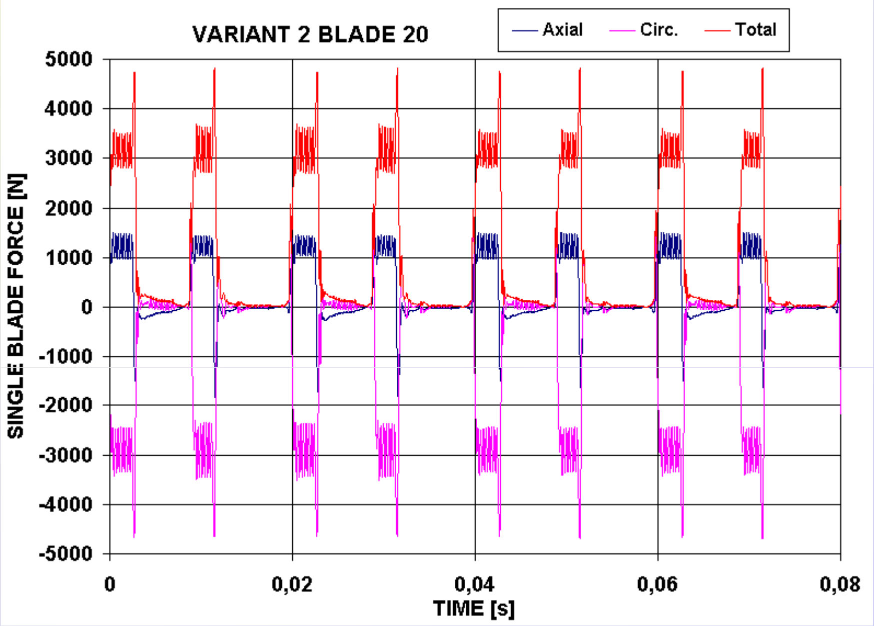
Partial admission turbines

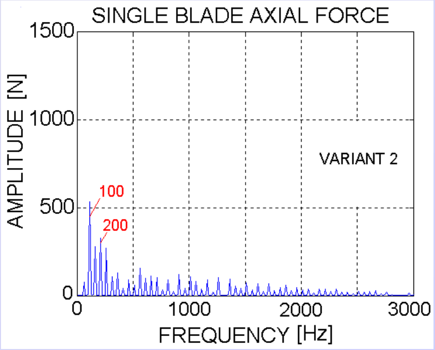
SINGLE ROTOR BLADE LOAD
(2D mid-span)

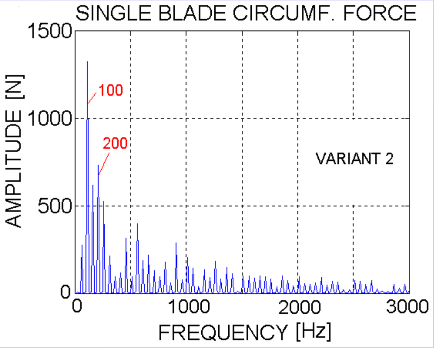






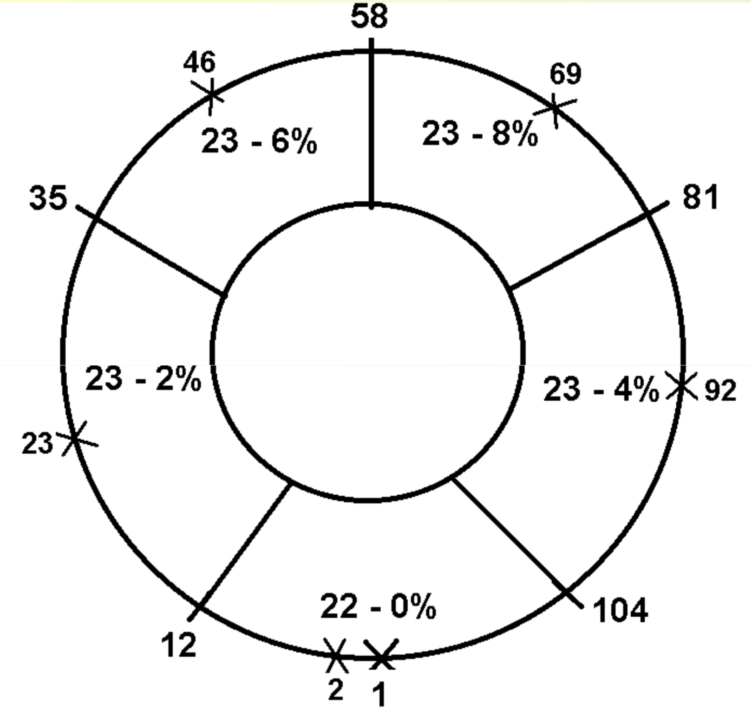




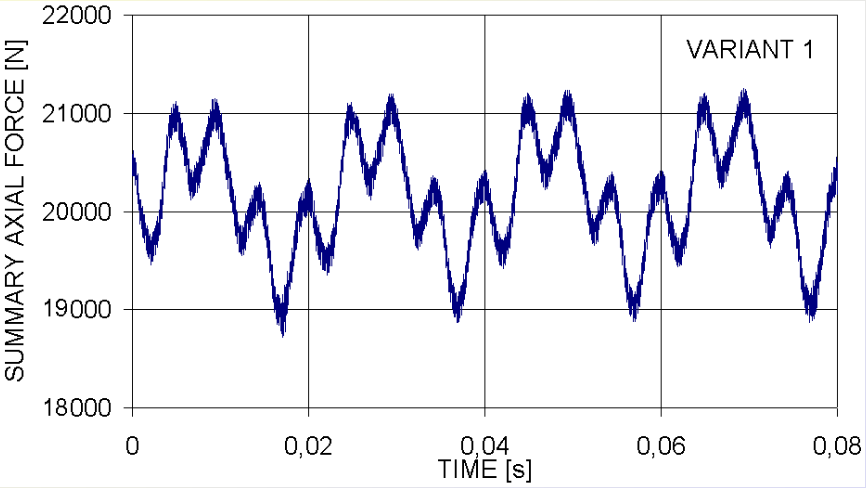


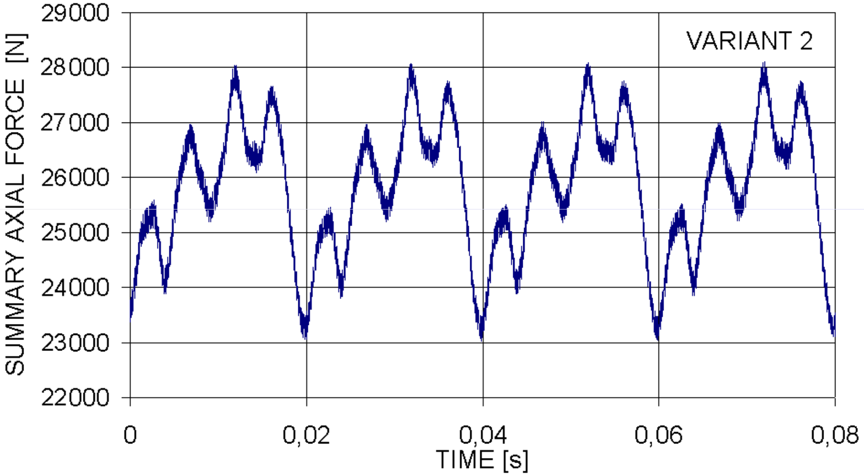
Partial admission turbines

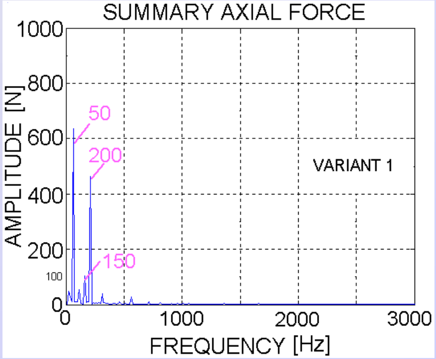
EFFECTS OF ROTOR BLADE MISTUNING OR GEOMETRICAL IMPERFECTION

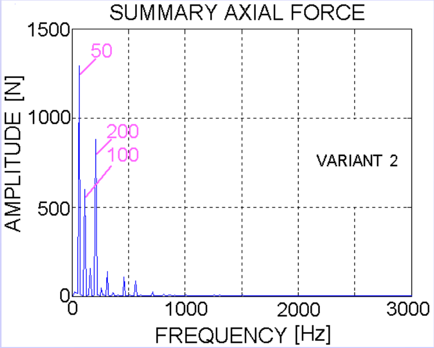


Schematic of changes in control stage rotor geometry.
Packages of blades with different blade thickness.

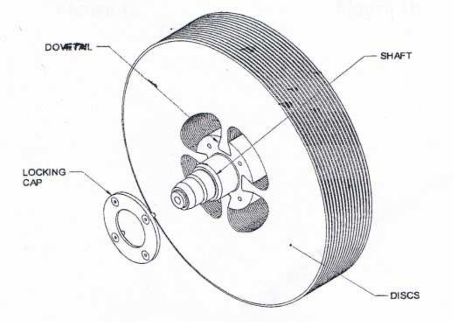


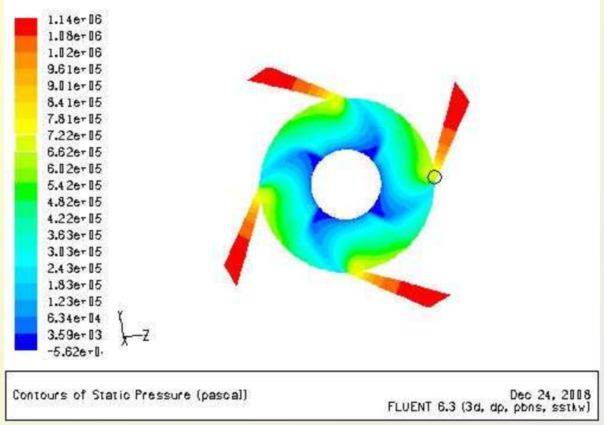


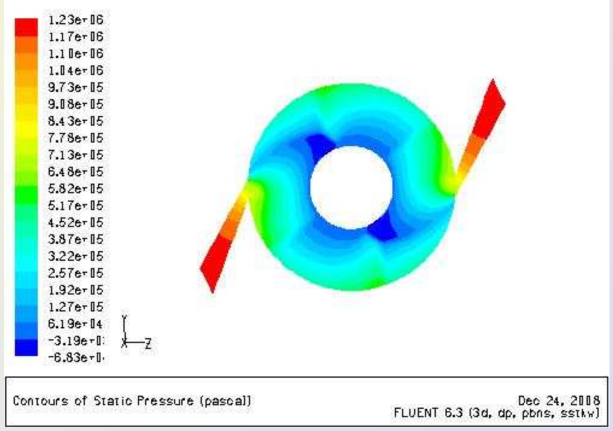


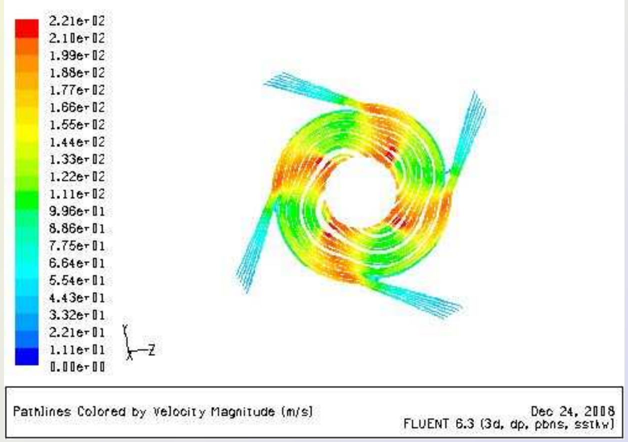


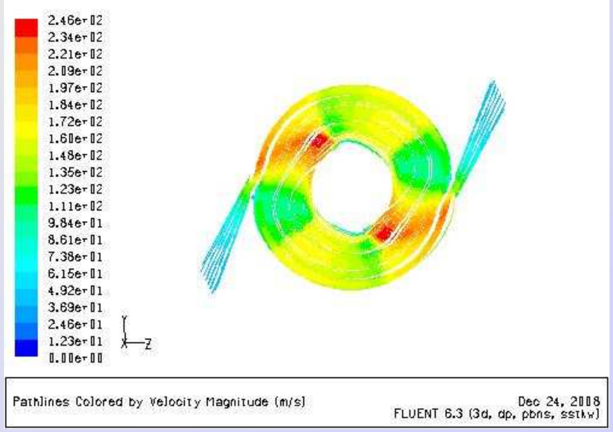
Tesla type Friction turbines









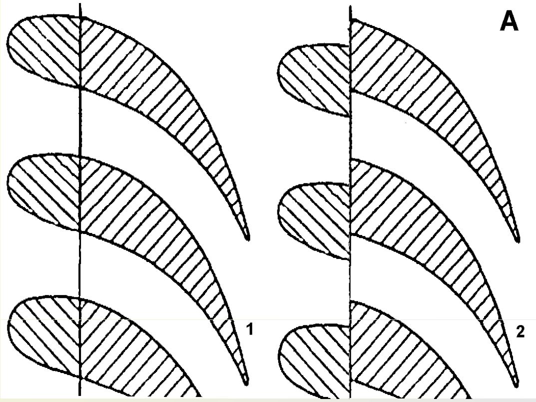


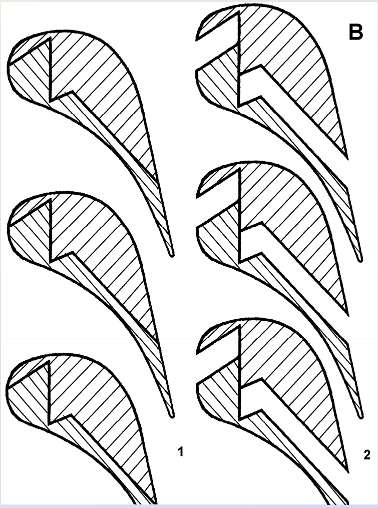
TESLA: n=18 000, SES36, p_{in}= 13,8 bar, T_{in}=400K, G = 0,38 kg/s, P = 1,63 kW

Source: P. Lampart K. Kosowski Ł. Jędrzejewski

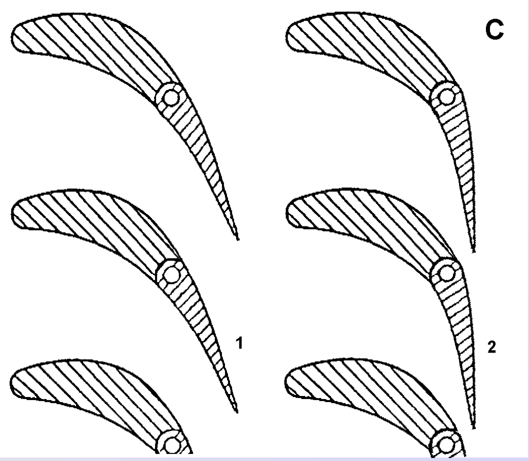
Adaptive control in LP cogeneration turbines

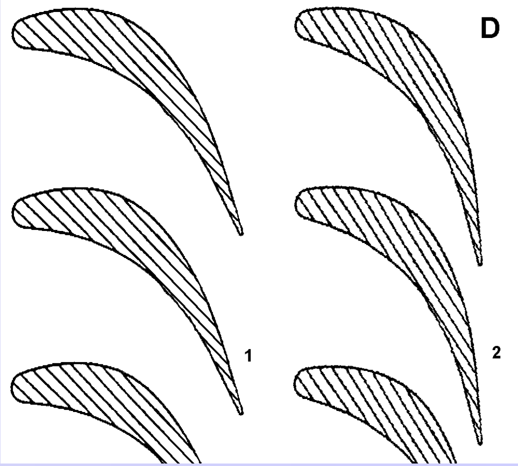
- **Cogeneration of electric energy and heat in heat and power turbines requires application of adaptive control to adapt them to variable operating conditions. The main element of adaptive control is the so-called adaptive stage of flexible geometry located directly downstream of the extraction point.**





Throttling nozzles (LMZ, ABB-Zamech, Alstom)





Source: P. Lampart R. Puzyrewski

The effect of adaptive control based on flap nozzles in a group of two LP stages in the case of cogeneration of electric energy and heat.

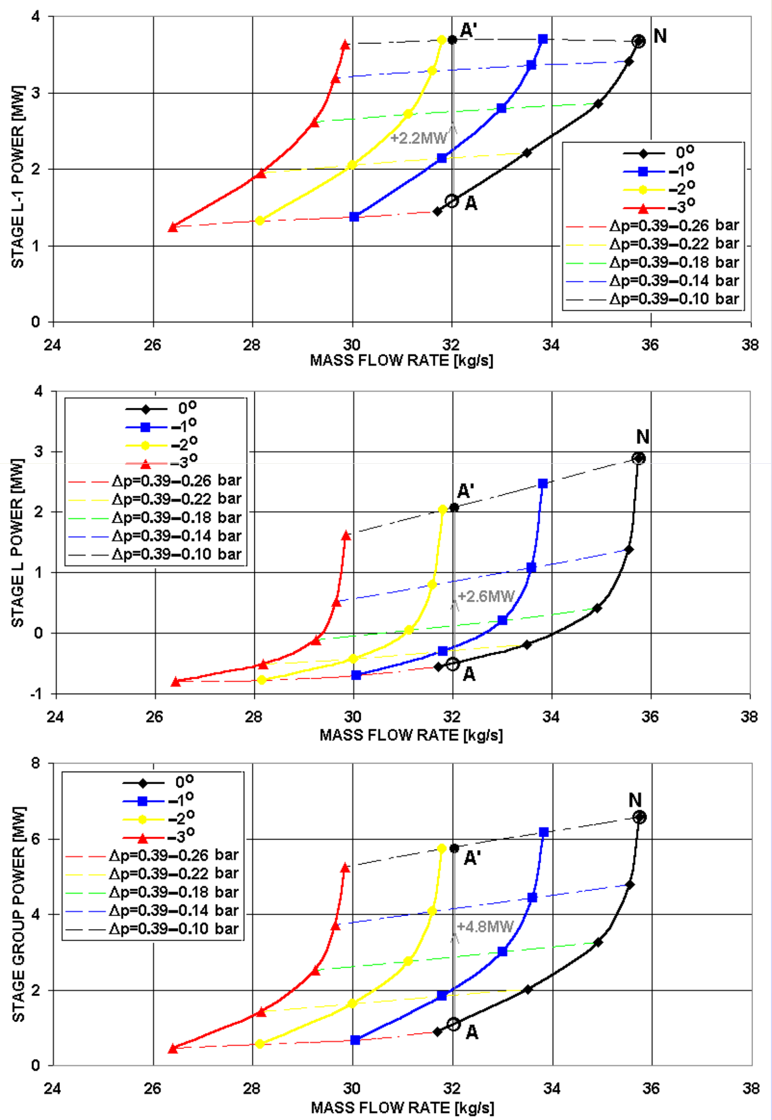
nominal o/p (N):
m_N = 35.6 kg/s,
Δp_N = 0.39 - 0.10 bar,
ζ_{L-1}= 12%, N_{L-1} = 3.7MW,
ζ_L = 20%, N_L = 2.8MW;

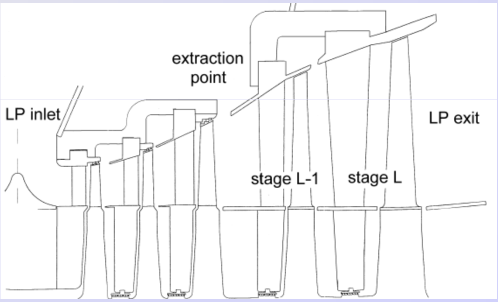
N→A

m_u = 3.6 kg/s, m_A = 32 kg/s,
p_{2A} = 0.25 bar,
ζ_{L-1} = 23%, N_{L-1} = 1.6MW
ζ_L> 100%, N_L = -0.5MW

A→A' (-1.8°)

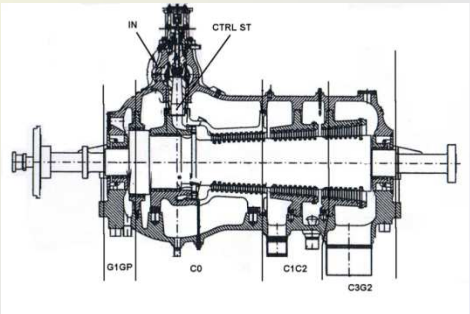
$m_{A'}$ = 32 kg/s, $p_{2A'}$ = 0.10 bar,
ζ_{L-1} = 13%, N_{L-1} = 3.8MW
ζ_L= 22%, N_L = 2.1MW





LP part of 60 MW extraction/condensing turbine

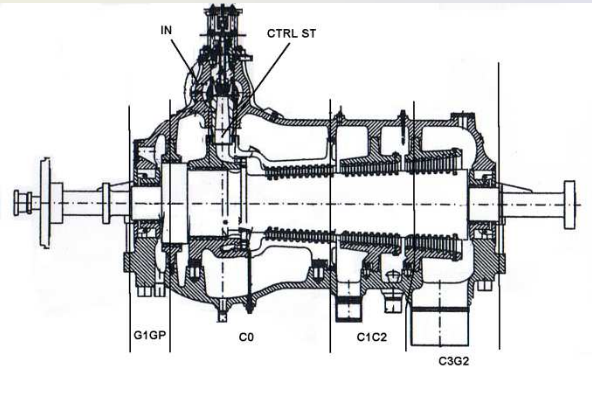
COGENERATION TURBINE PREHEATING at START-UP



- During start-up from a cold state the metal temperature increases by 500K
- This is accompanied by elongation of the metal and increase of stresses in the metal
- Relative elongations of casing and rotor appear. Clearances are reduced. Friction of metal against metal can occur.
- Frequent changes of heat load and large heating rates
  lead to increased unsteady stresses, then thermal fatigue and metal cracking
- Permanent deformations can occur

Source: R. Rządkowski P. Lampart

HEATING-UP PROCEDURE



- **First phases – condensation heat transfer. Dewatering system is open until superheated steam appears at the exit.**
- **Subsequent phases – convective heat transfer from superheated steam.**

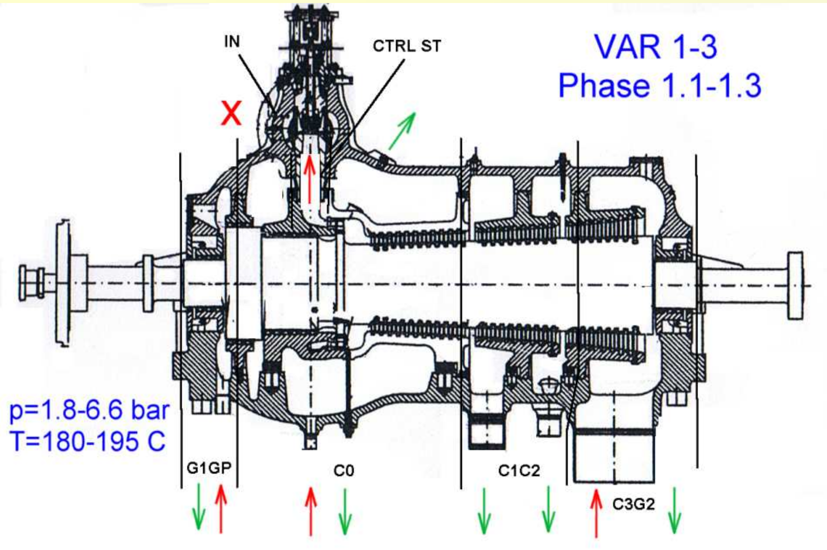
Measurement of absolute and relative elongations

If maximum values are exceeded turbine is shut down

CFD CALCULATIONS (PROGRAM FLUENT)

- **Conjugated heat and flow calculations:**
  - **within the flow region (blading system, sealings, intercasing chambers, inlet and outlet pipes - model RANS**
  - **within the metal region (shaft, inner casing, outer casing, shield) – energy conservation equation**
  - **boundary conditions – no heat flow at the shield**
- **Evaluation of surface heat flux to the casing and rotor**

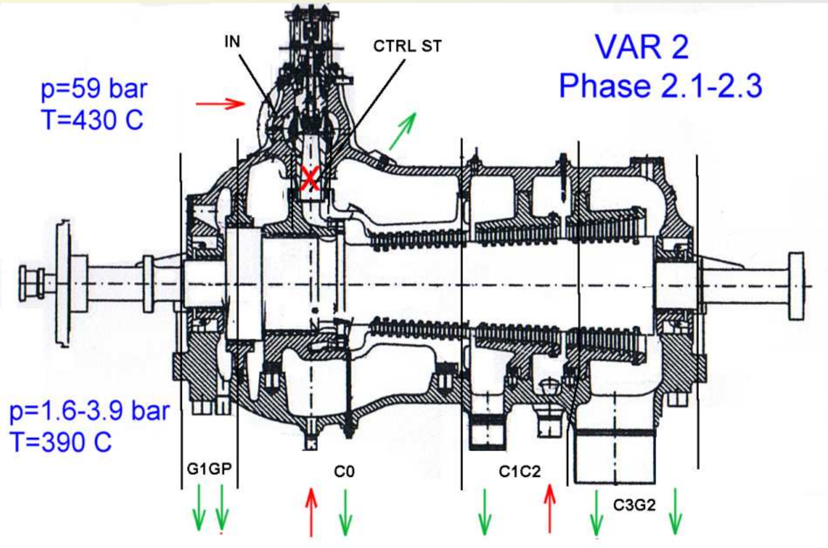
30 min



⇨ Cut-off valve closed
⇨ Steam supplied to the outlet

⇨ Saturation temperature T_s=116-162^{o}C
⇨ Film condensation heat transfer

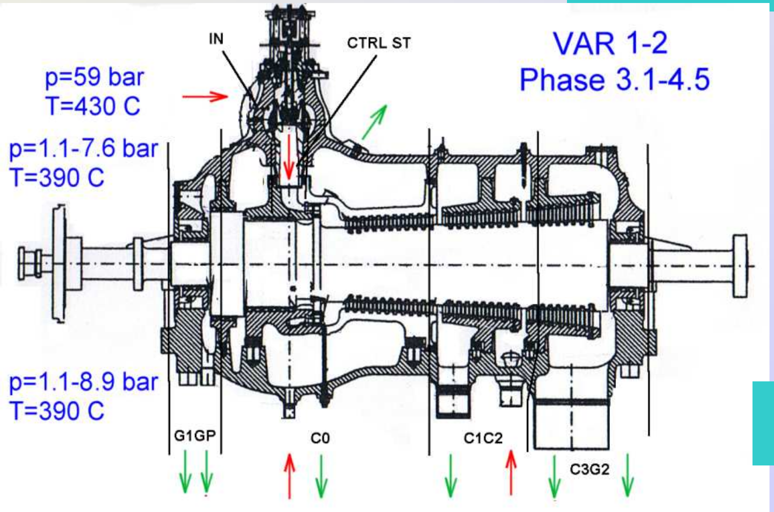
60 min



⇨ Control valves closed
⇨Steam supplied to the intercasing space.
⇨Live steam at the inlet

⇨ Convective heat transfer from superheated steam (condensation at the inlet pipe)

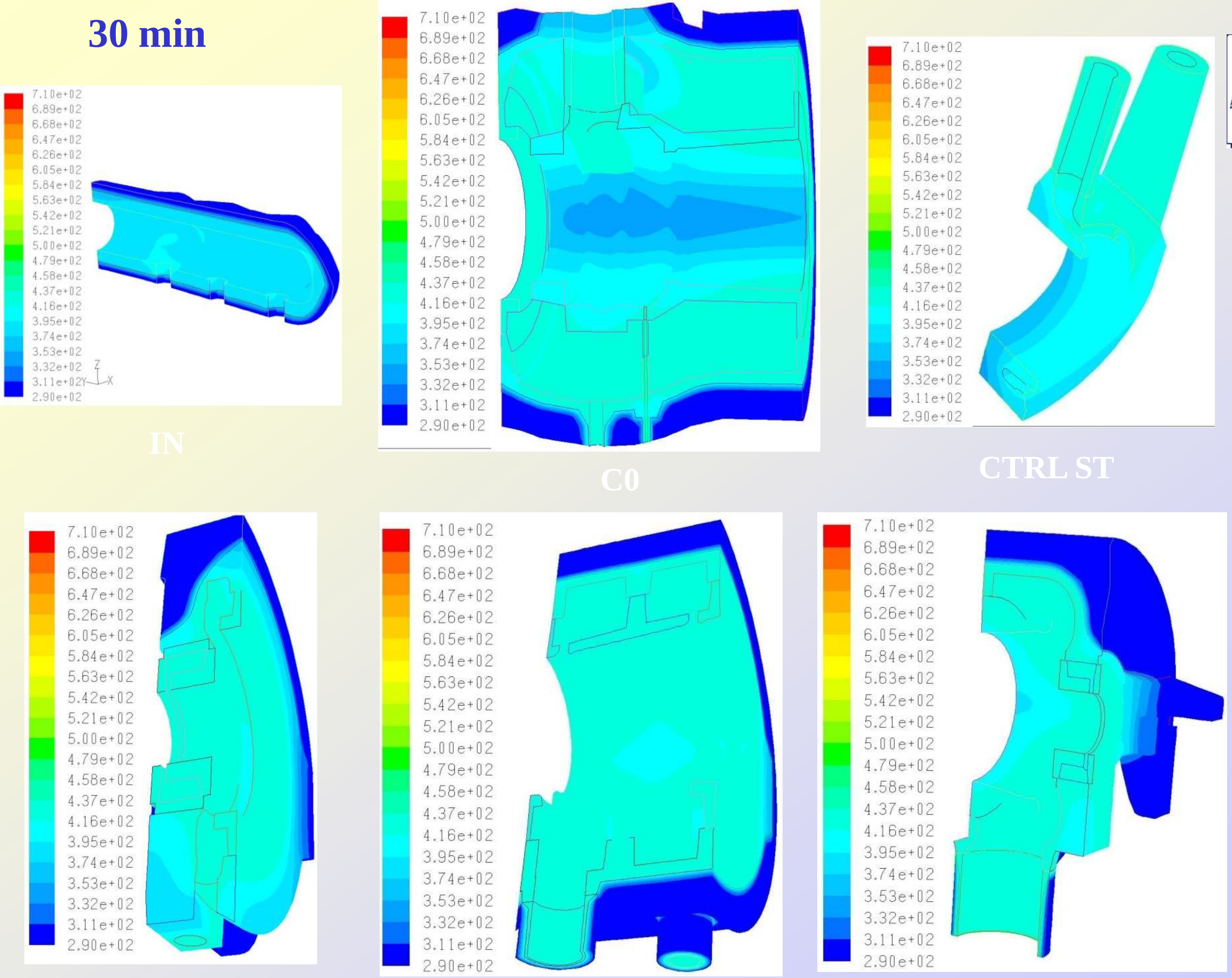
115 min



⇨ Control valves successive opening
⇨ Live steam supply.
⇨ Rotational velocity increase

⇨ Heat transfer from superheated steam

30 min



IN

C0

CTRL ST

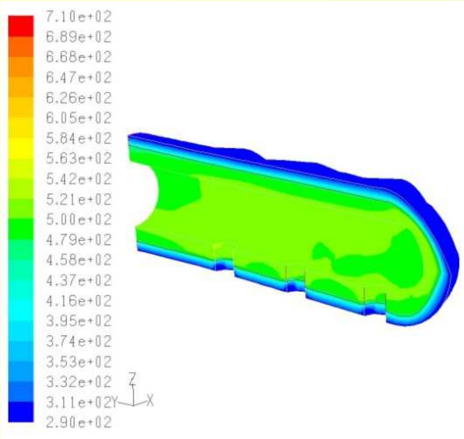
G1GP

C1C2

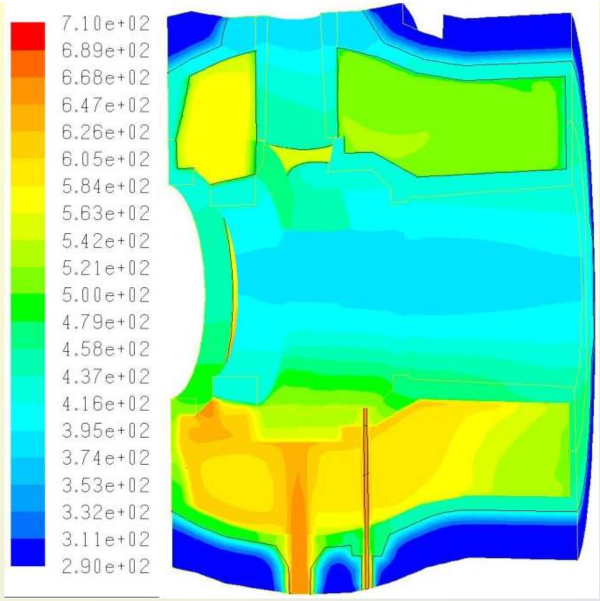
C3G2

Temperature in the fluid, metal and shield after 30 min of heating [K]

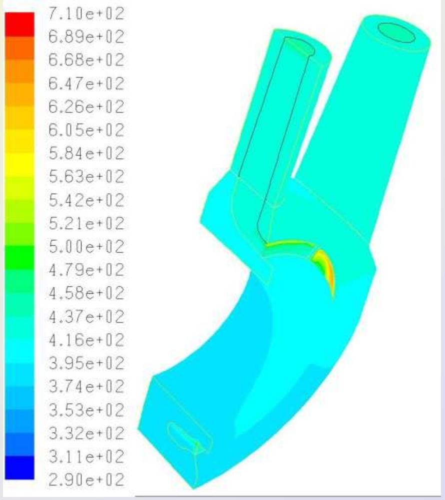
60 min



IN



C0



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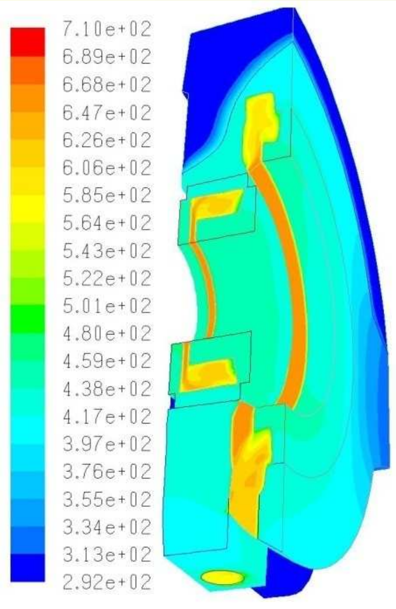
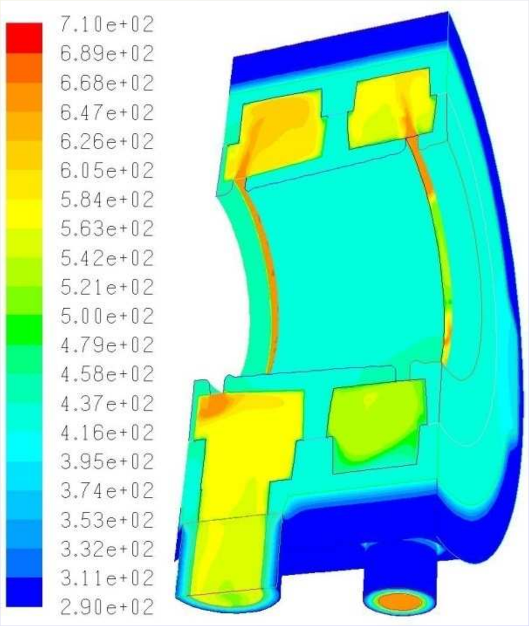
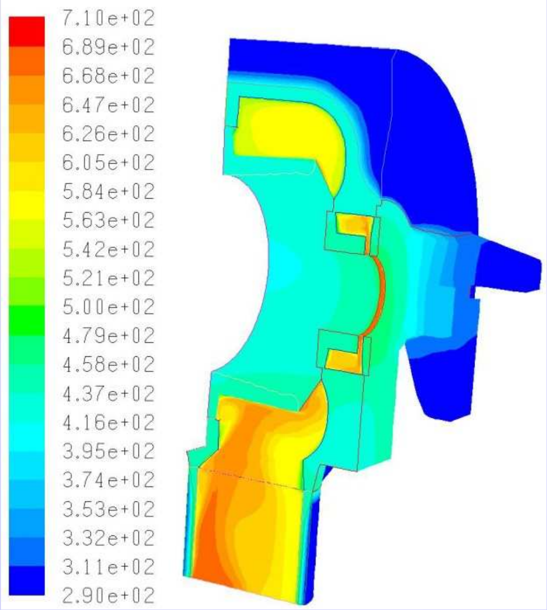


G1GP



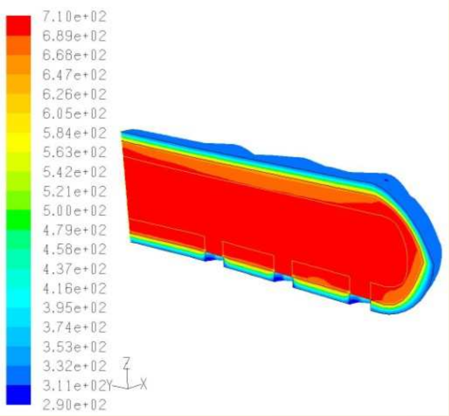
C1C2



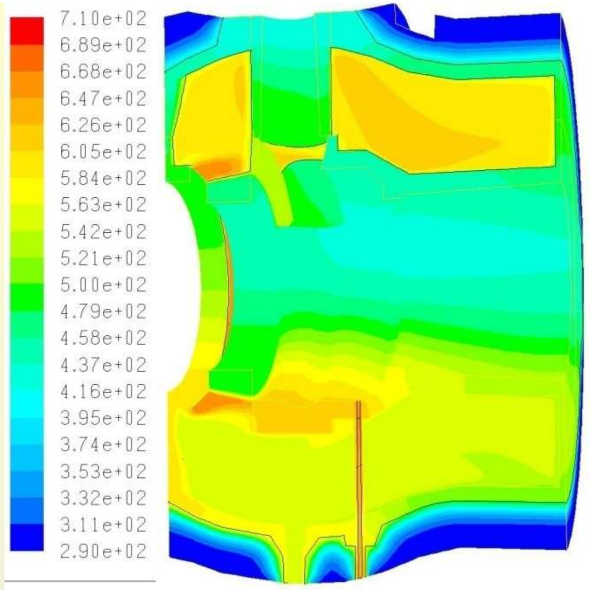
C3G2

Temperature in the fluid, metal and shield after 60 min of heating [K]

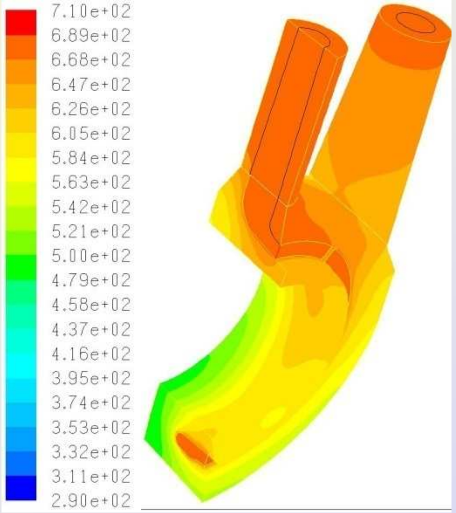
135 min



IN



C0



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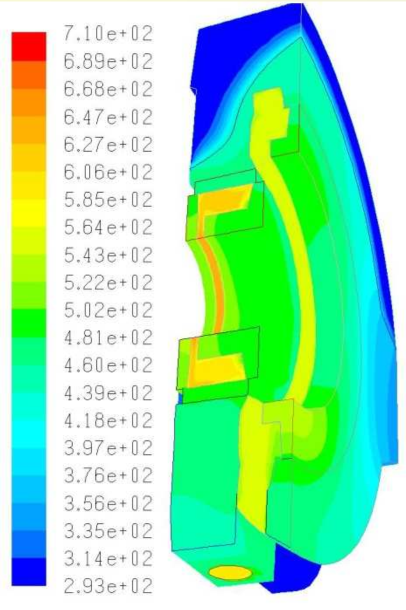
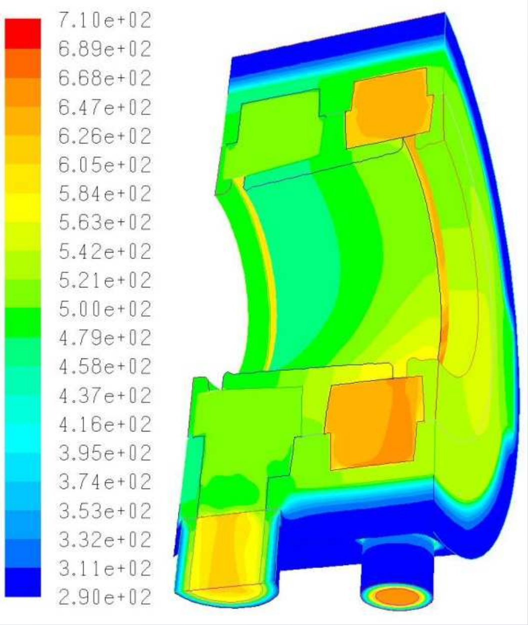
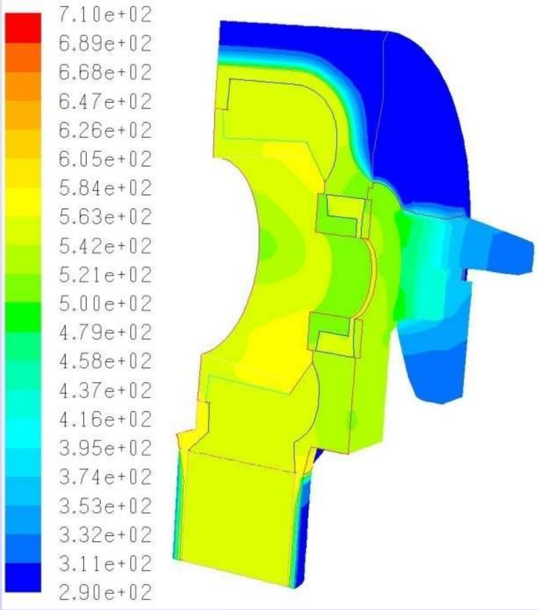


G1GP

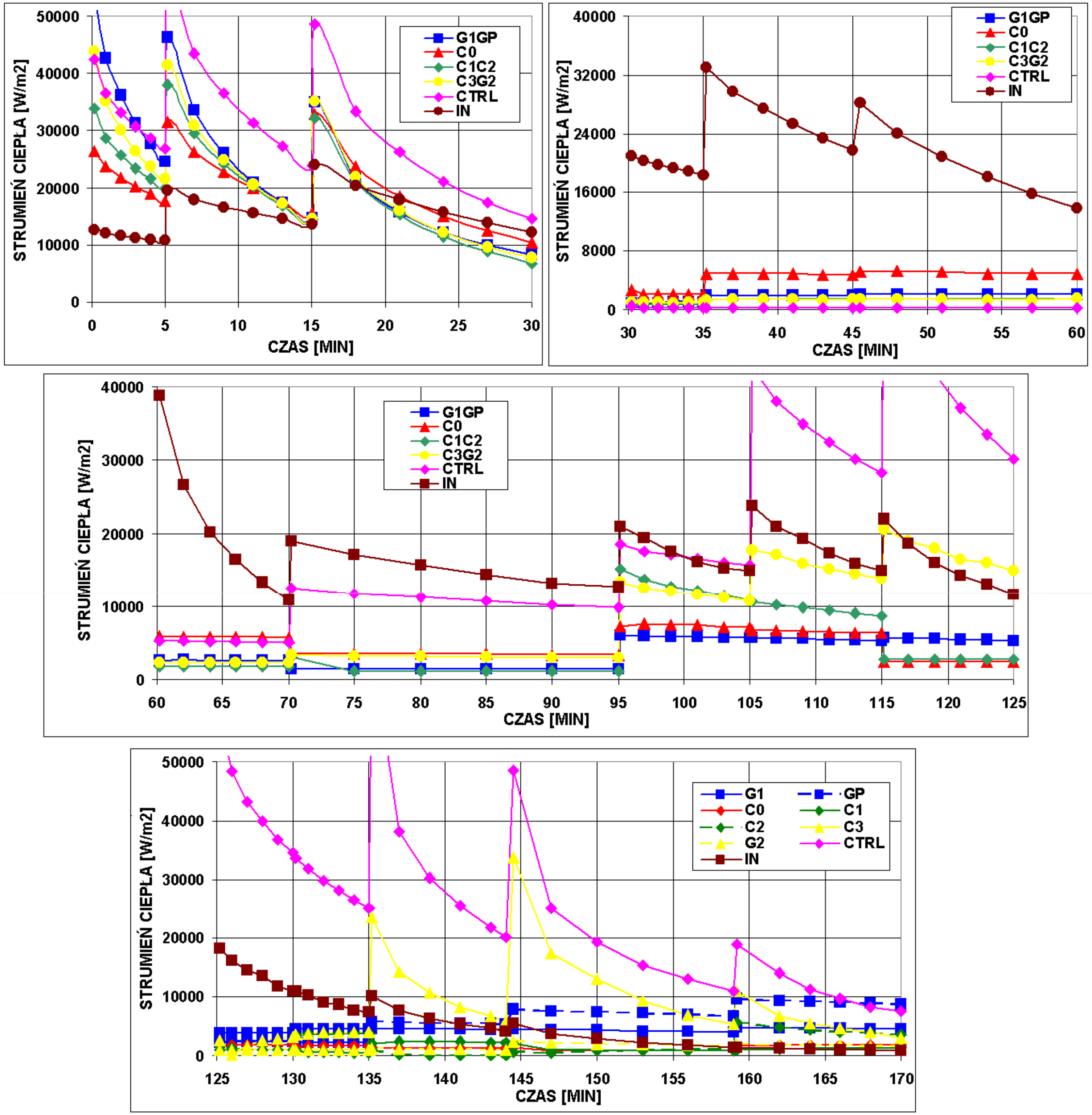


C1C2

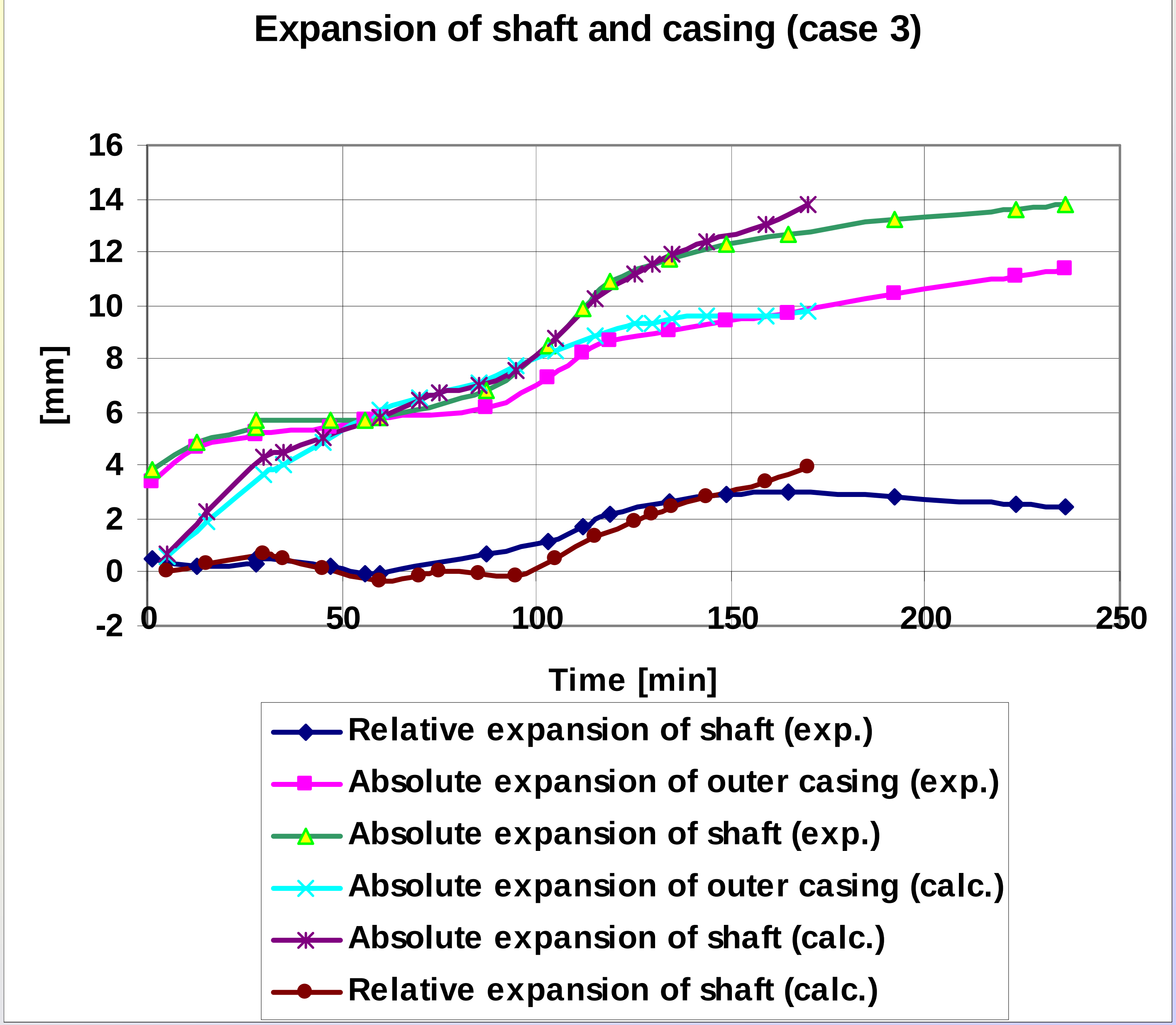


C3G2

Temperature in the fluid, metal and shield after 135 min of heating [K]



Mean surface heat flux during turbine preheating



Relative and absolute expansions of casing and shaft