Piston engine with Brayton cycle

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Authors:
Baklanova Y.
Kotov V.M.
Institute of Atomic Energy NNC RK

Unrenewable power sources

Many years ago

Gas

Oil

Shale

Peat

Coal

Renewable sources and compatible energy transformers

Solar

Biomass

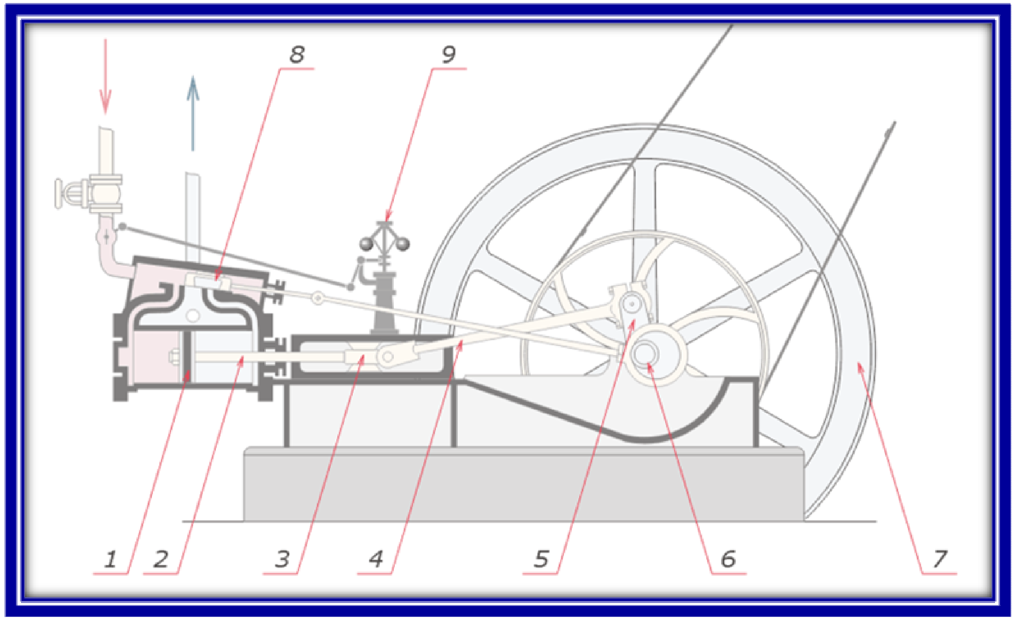
Steam machines with Rankin Cycle

Stirling engines
(on the base of T-V processes)

Erickson engines
(on the base of T-P processes)

Engines on the base of turbo-machines
with Brayton cycle
(on the base of P-A processes)

Steam Machines



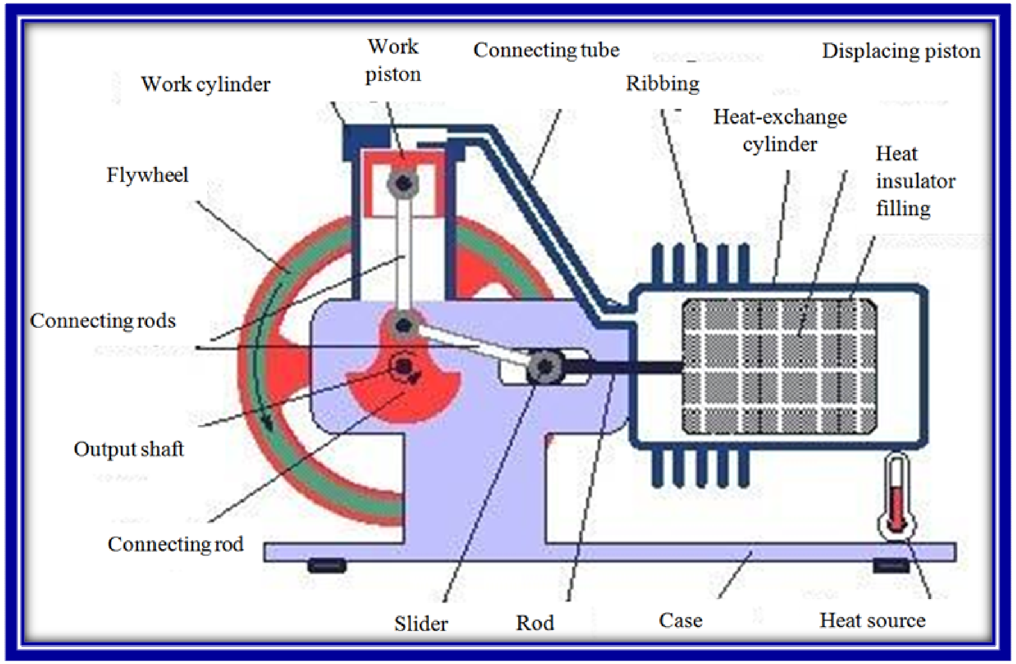
1- piston, 2 – piston rod, 3 – slider, 4 – connecting rod, 5 – crankshaft, 6 – eccentric for the valve, 7 – flywheel, 8 – valve, 9 – centrifugal governor

Scheme of the horizontal one-piston double-acting high pressure steam machine

<u>Shortages</u>:

- Low effectiveness,
- Large specific fuel charge,
- Large engine mass and its auxiliary components.

Stirling and Erickson engines



Stirling engine scheme

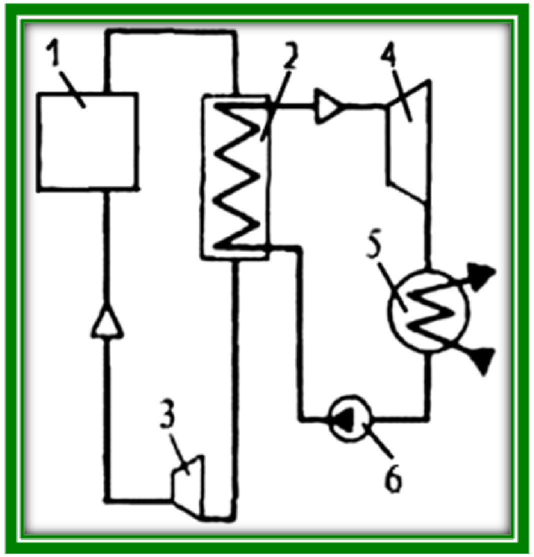
Shortages:

▪Approaching of work process to ideal at small expansions, when work characteristics is the worst;

▪Thermal energy recuperation necessity between anisothermic processes. Heat flow of recuperation is multiply larger than output power.

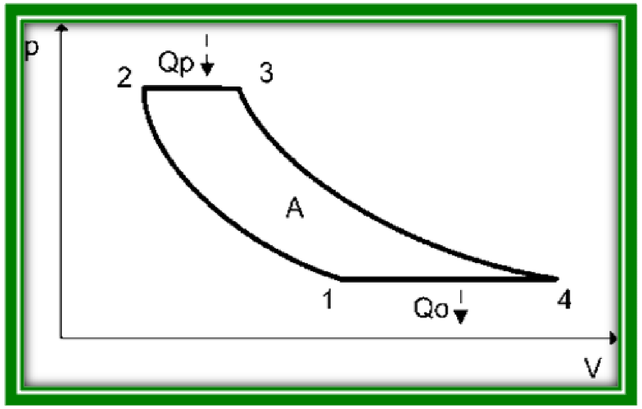
Acceptable effectiveness is at maximal cycle temperature 1000 ^{o}C.

Turbomachines working Brayton cycle



1 — reactor; 2 — steam generator; 3 — gas blower; 4 — steam turbine; 5 — condenser; 6 — feed pump

Installation scheme for electricity production

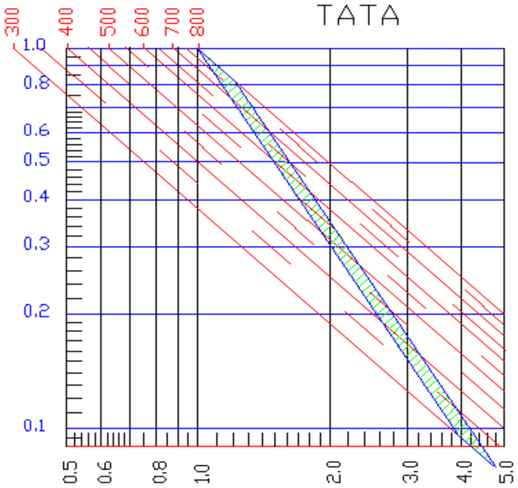


Ideal Brayton cycle is made of
1—2 Isentropic compression.
2—3 Isobaric energy feed.
3—4 Isentropic expansion.
4—1 Isobaric energy withdrawal.

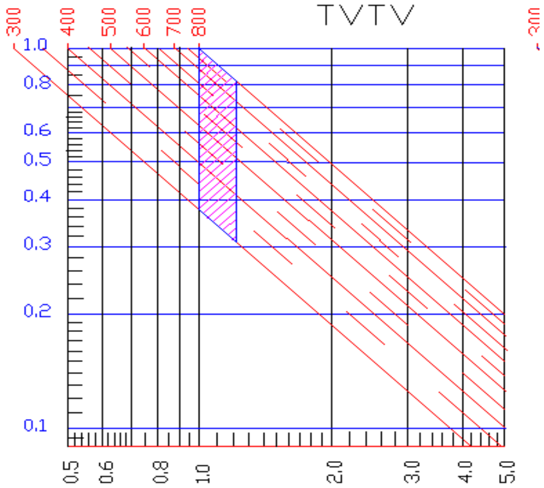
<u>Shortage</u>:

- Small energy losses at transmission from gas flow to blades leads to large total losses.

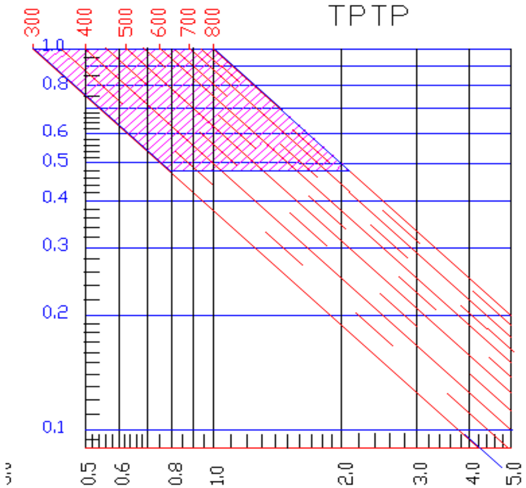
Engine cycles with gaseous work medium



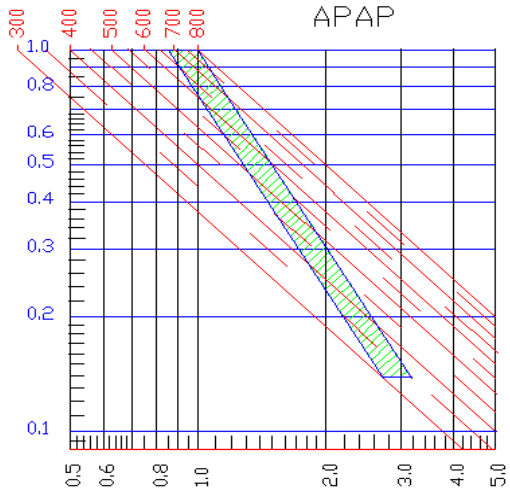
Carno cycle



Ideal cycle for Stirling



Ideal cycle for Erickson



Brayton cycle

Work options for piston engine with Brayton cycle

A. With small expansion degree ε, when $\varepsilon < \varepsilon_{kr}$. In this field recuperative thermal energy transmission is needed from isobaric expansion process to isobaric compression process.

B. With larger expansion degree ε, when $\varepsilon_{max} > \varepsilon > \varepsilon_{\kappa p}$. In this field recuperative thermal energy transmission is not needed.

C. In the field with expansion degree $\varepsilon > \varepsilon_{max}$ engine does not work. This fact is distinction of Brayton cycle from other cycles shown at figure 1.

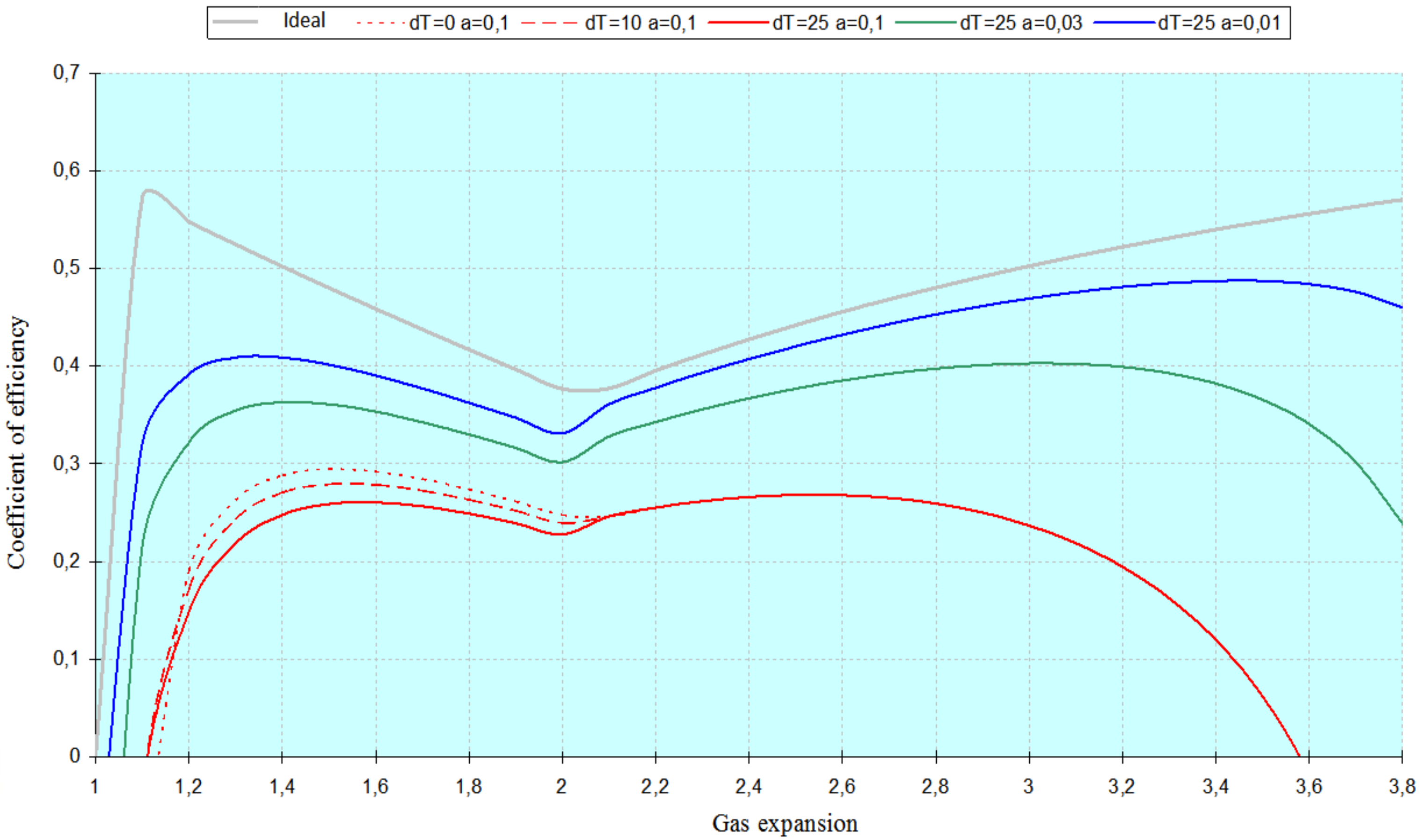
Effectiveness calculation for machine with Brayton cycle

$$Effectiveness=\begin{cases}\varepsilon<\varepsilon_{\kappa p}, & \dfrac{R}{\mu}\dfrac{k}{k-1}\dfrac{\varepsilon^{k-1}\dfrac{T_3}{T_1}\left(a_{meh}\dfrac{k-2}{k}-1\right)-\dfrac{1}{\varepsilon^{k-1}}\left(a_{meh}\dfrac{k-2}{k}+1\right)+1+\dfrac{T_3}{T_1}-a_{meh}\left(1-\dfrac{T_3}{T_1}\right)}{C_p\left(1-\dfrac{1}{\varepsilon^{x-1}}+\dfrac{dT}{T_1}\right)}, \\ \varepsilon>=\varepsilon_{\kappa p}, & \dfrac{R}{\mu}\dfrac{k}{k-1}\dfrac{\varepsilon^{k-1}\dfrac{T_3}{T_1}\left(a_{meh}\dfrac{k-2}{k}-1\right)-\dfrac{1}{\varepsilon^{x-1}}\left(a_{meh}\dfrac{k-2}{k}+1\right)+1+\dfrac{T_3}{T_1}-a_{meh}\left(1-\dfrac{T_3}{T_1}\right)}{C_p\left(1-\dfrac{T_3}{T_1}\varepsilon^{k-1}\right)}.\end{cases} \quad (1)$$

ε – the degree of gas expansion in the adiabatic process;
k – adiabatic index;
μ – molecular weight of gas, g/mole;
a_{mech} – the level of mechanical energy losses in the separate processes, relative units;
T1 – maximum temperature of the cycle, К;
T3 – minimum temperature of the cycle, К;
Cp – gas thermal capacity, J/g;
dT – the temperature difference between the gas flows in the recovery heat exchanger with countercurrent flow, К;
R – absolute gas constant.

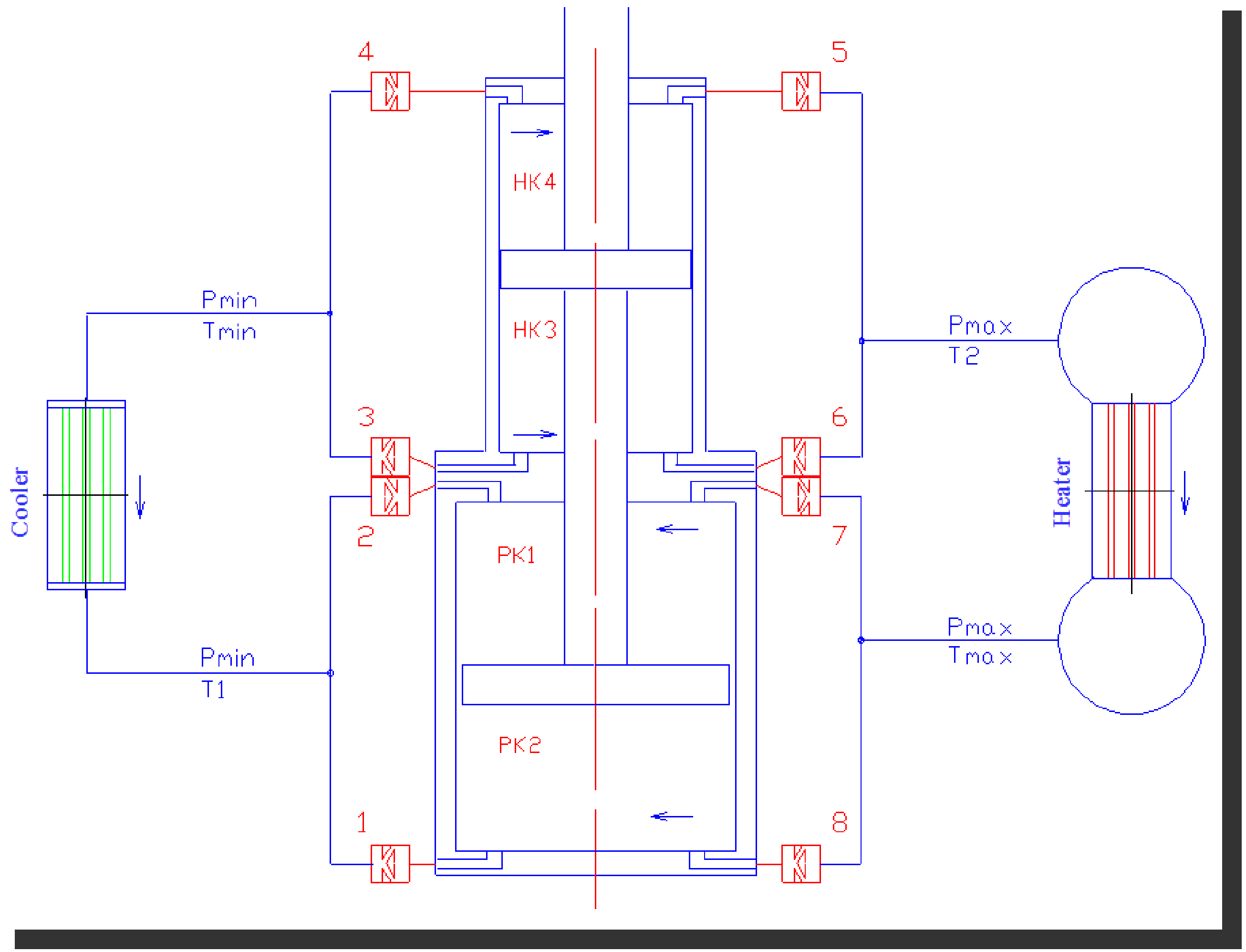
$$\varepsilon_{\kappa p}=\left(\frac{-dT+\sqrt{dT^2+4T_1T_3}}{2T_3}\right)^{1-k}$$

Brayton cycle effectiveness

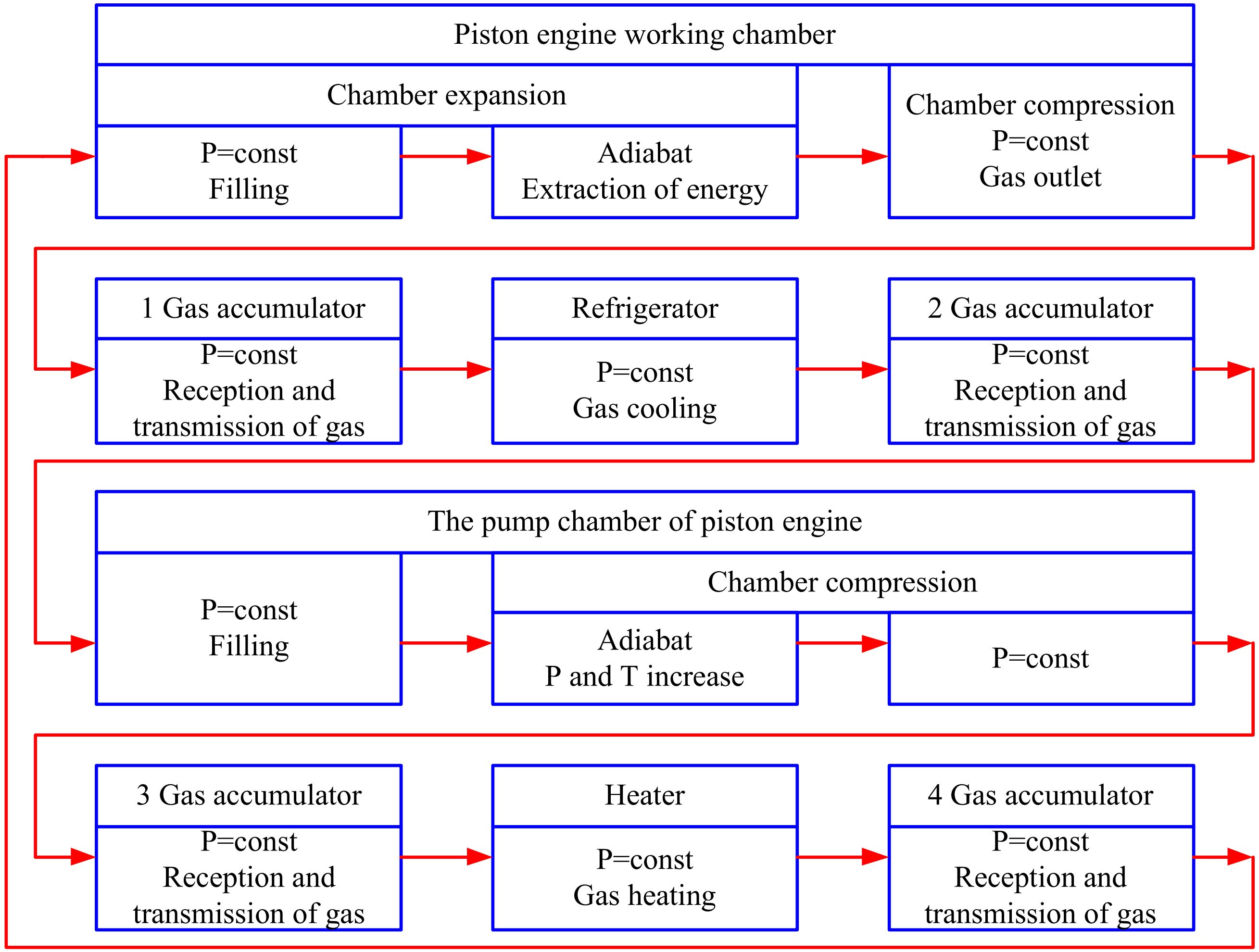


Brayton cycle with maximal cycle temperature 500 ºC and minimal cycle temperature 27 ºC effectiveness dependence on expansion degree. Working medium – helium.

APAP engine scheme with common chamber-piston group



Process sequence in piston APAP cycle



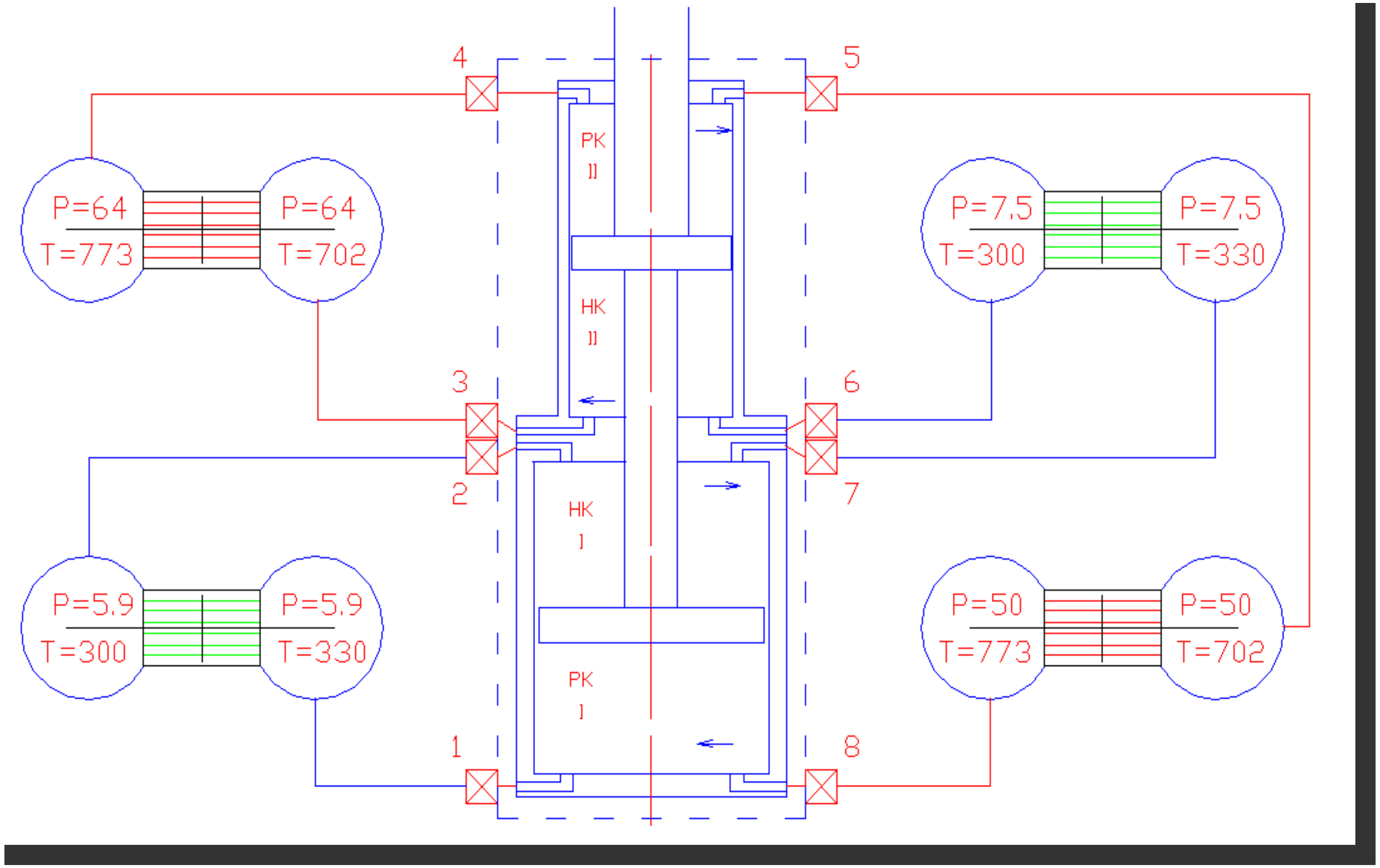
Engine effectiveness

$$Eff_{in} = Eff \cdot \psi \qquad (2)$$

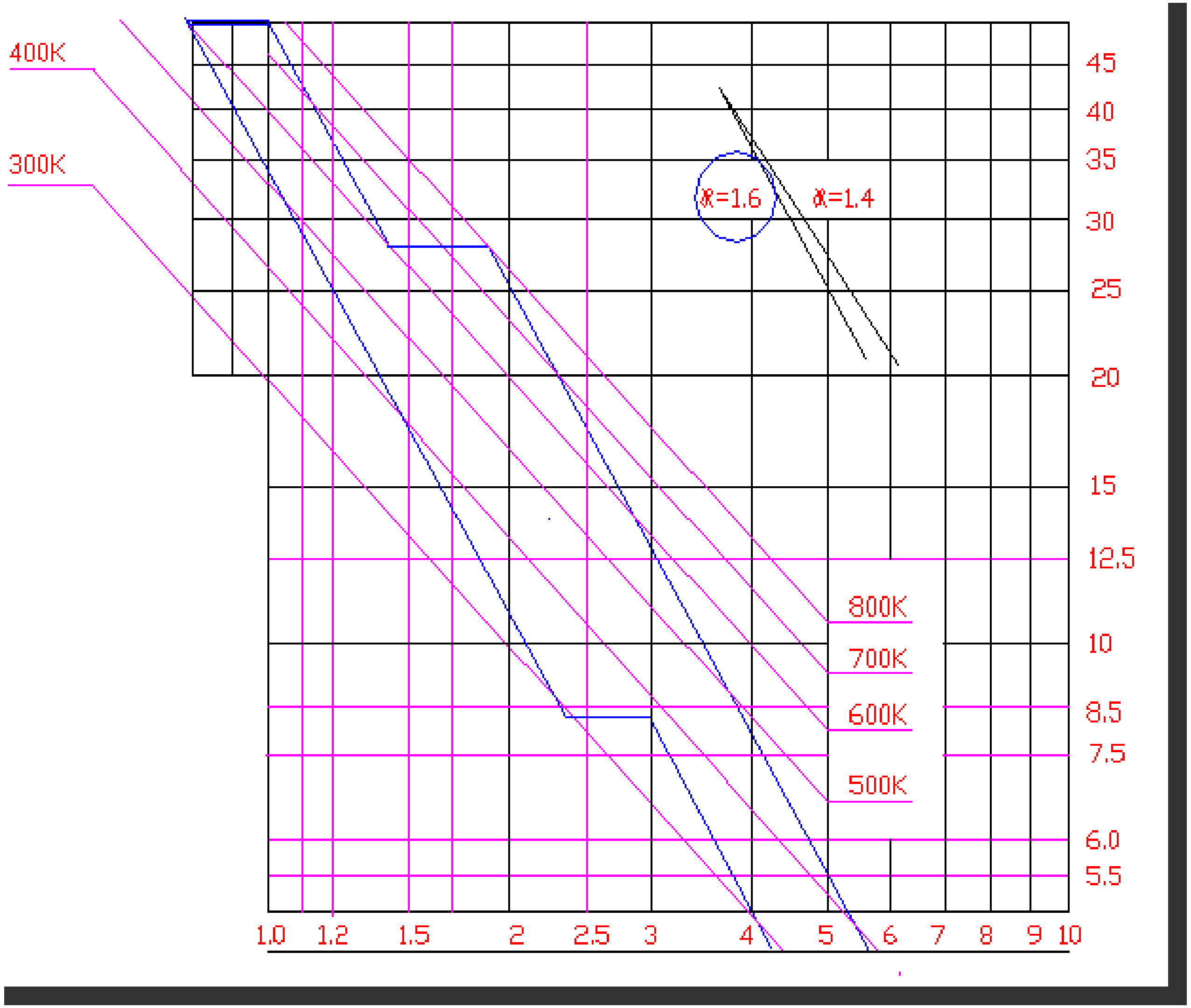
Eff_{in} – total effectiveness;
Eff – is effectiveness calculated in equation (1);
Ψ – system «piston group – connecting rod – crankshaft» effectiveness.

Value of Ψ can achieve 0.97-0.99.

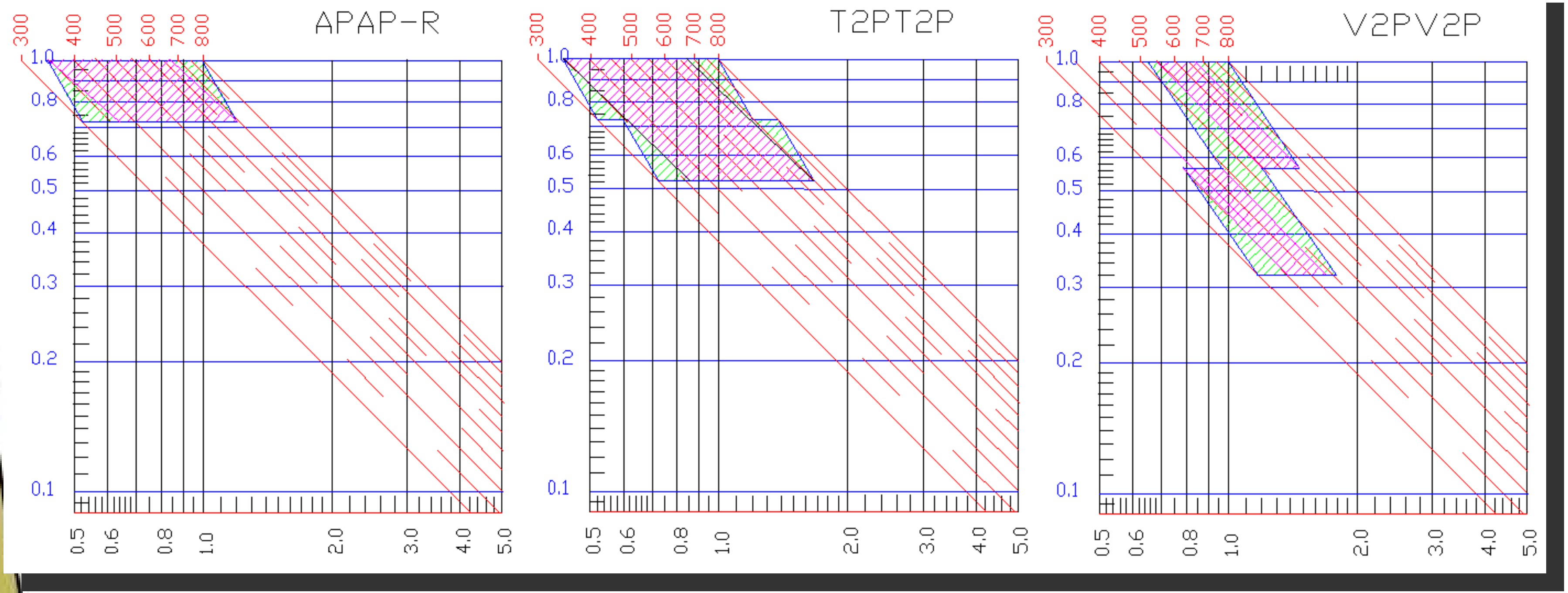
Scheme of engine on the base of AP processes with approach to TATA processes



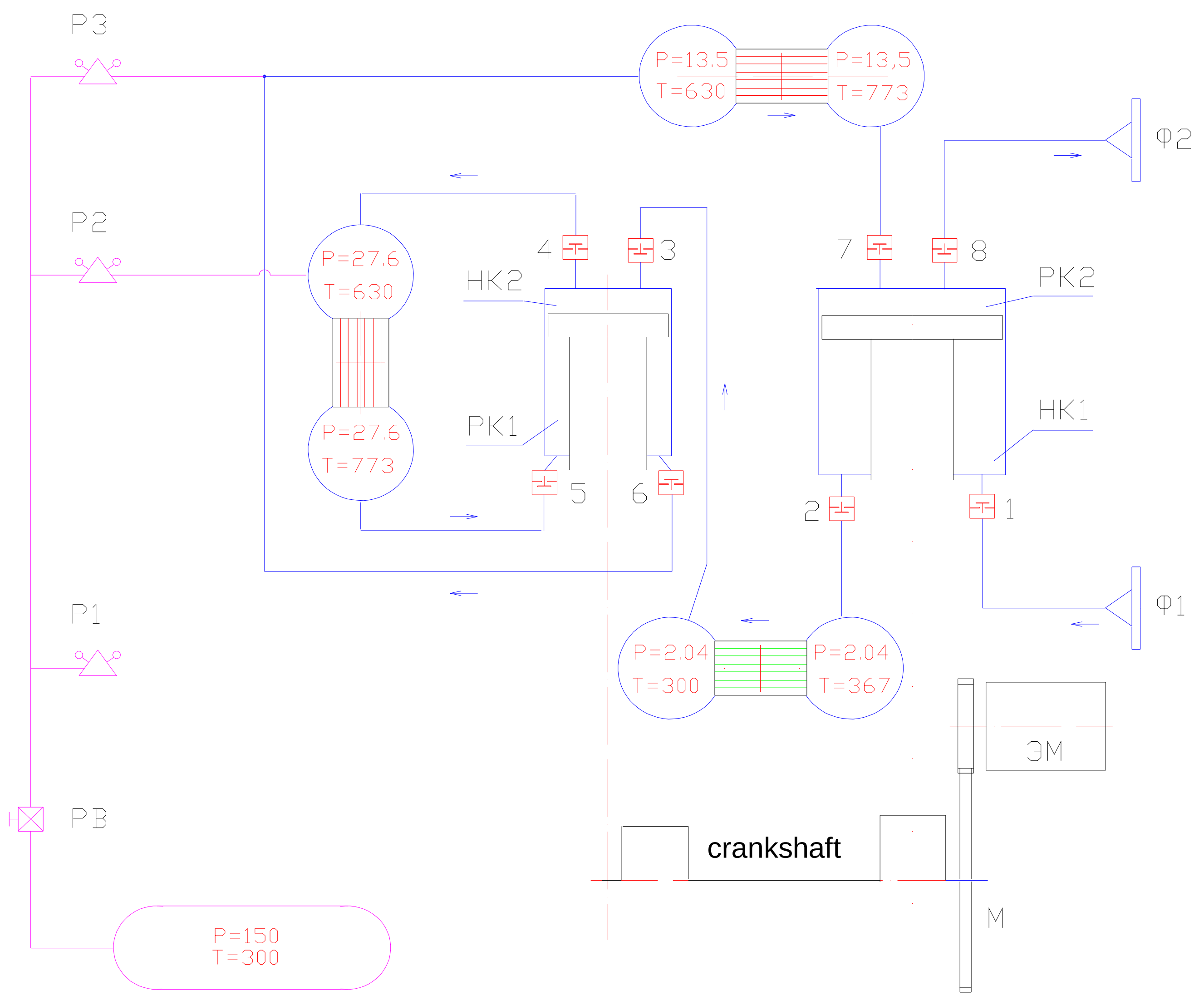
Process scheme for the cycle with discrete approach to TATA processes



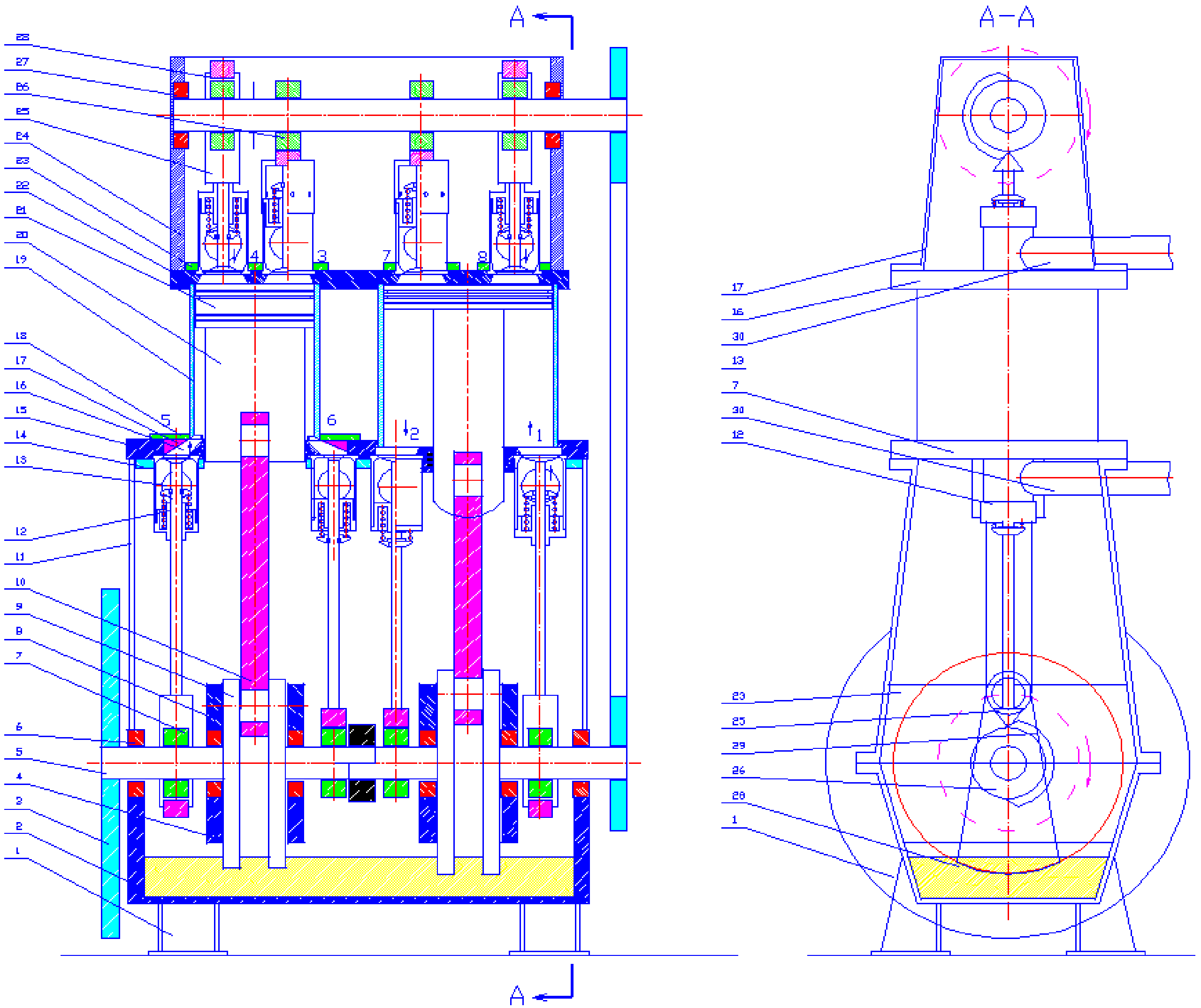
Cycle schemes, which enable specific volume power increase



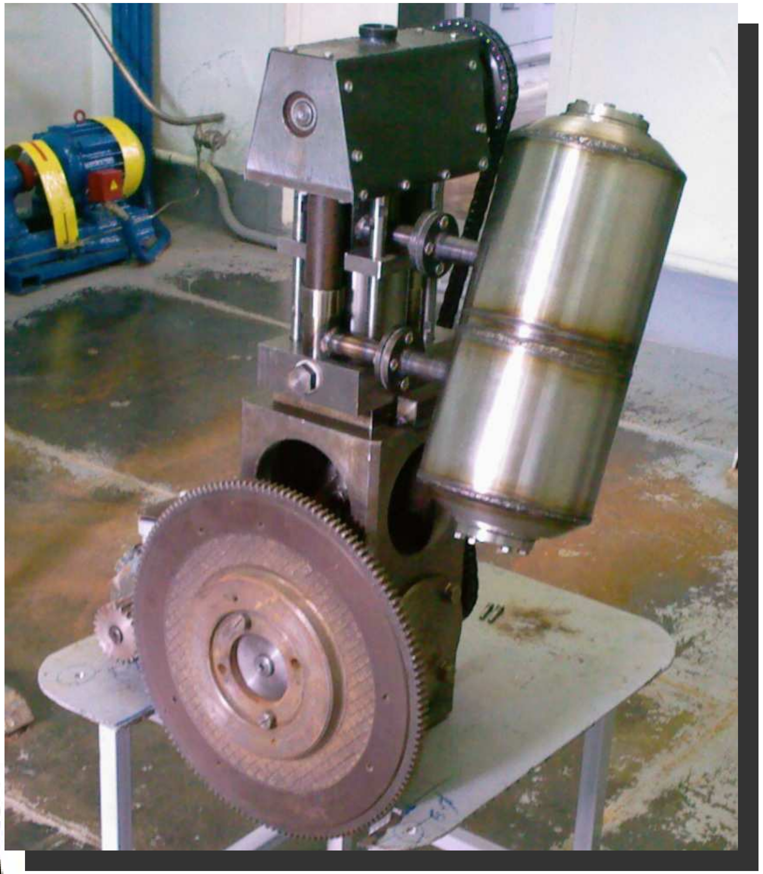
Scheme of engine with open loop air cycle



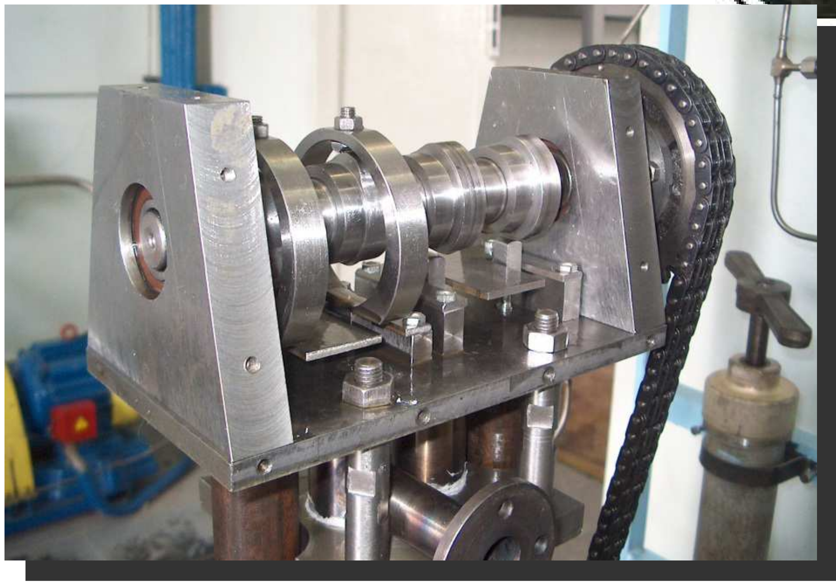
Open loop air cycle engine design



APAP engine model



General view of the model



Gas-distributing mechanism. Cover is removed.

Piston machine model characteristics:

Piston machine model has following parameters:

Piston diameter	79 mm;
Displacer diameter	46 mm;
Height of cylinder	100 mm;
Height of piston	18.5 mm;
Piston run	80 mm;
Total volume of heater tanks	5.3 liter.

Characteristics comparison of thermal engines

	Engine type	T max, ^{o}C	effectiveness, %		$effectiveness_p$/ $effectiveness_к$	¥
			From Carno	Real		
1	Rankin with large W	500	61	Up to 45	0,73	no
2	Rankin with small W	300	48	Up to 15	0,31	yes
3	Stirling	~1000	76,5	Up to 40	0,52	yes
4	Brayton (turbo)	~1000	76,5	Up to 40	0,52	no
5	internal-combustion engine, Disel	~2500	89	Up to 40	0,45	no
6	internal-combustion engine, Otto	~2500	89	Up to 30	0,34	no
7	APAP	~500	61	Up to 50	0,82	yes

Conclusion

- Piston engine with use of external heat supply to cycle on the base of isobaric and adiabatic processes (Brayton cycle) provides opportunity of effectiveness increase up to 50 % at при comparatively low maximal cycle temperature 500 ^{o}C.
- Work conditions of piston engine elements for APAP cycle are obtained.
- Engine design for its specific power increase in comparison to specific power of the simplest design are obtained.
- Open loop air cycle engine design, which supplies maximal simplicity and its cooler power decrease is obtained.

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Thank you for your attention!