PUMPS AND COMPRESSORS OF NPP

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LITERATURE

Centrifugal Pumps by Johann Friedrich Gülich

- https://link.springer.com/book/10.1007/978-3-030-14788-4

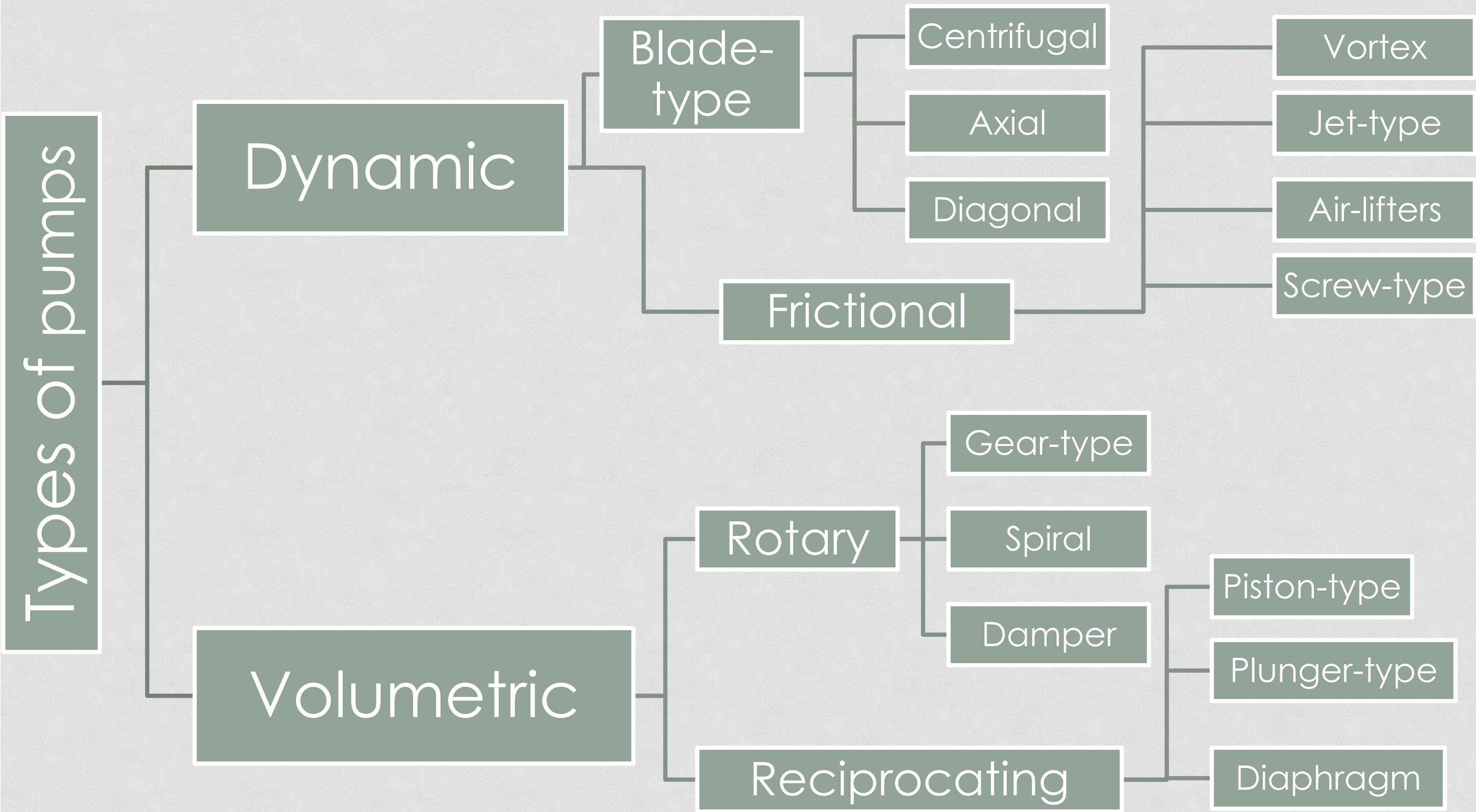
PUMPS, COMPRESSORS AND BLOWERS

- Pumps, ventilators, compressors and blowers are machines which serve to move fluids and gases by increasing its potential and kinetic energy.

- Pumps – devices used to move and/or increase pressure of liquid incompressible fluids.

- Ventilators, compressors and blowers are devices for moving and increasing pressure of gases:
  - Ventilators – devices with pressure ratio below 1,15.
  - Blowers – devices with pressure ratio between 1,15 and 3.
  - Compressors – devices with pressure ratio above 3.

CLASSIFICATION OF PUMPS BY OPERATIONAL PRINCIPLE

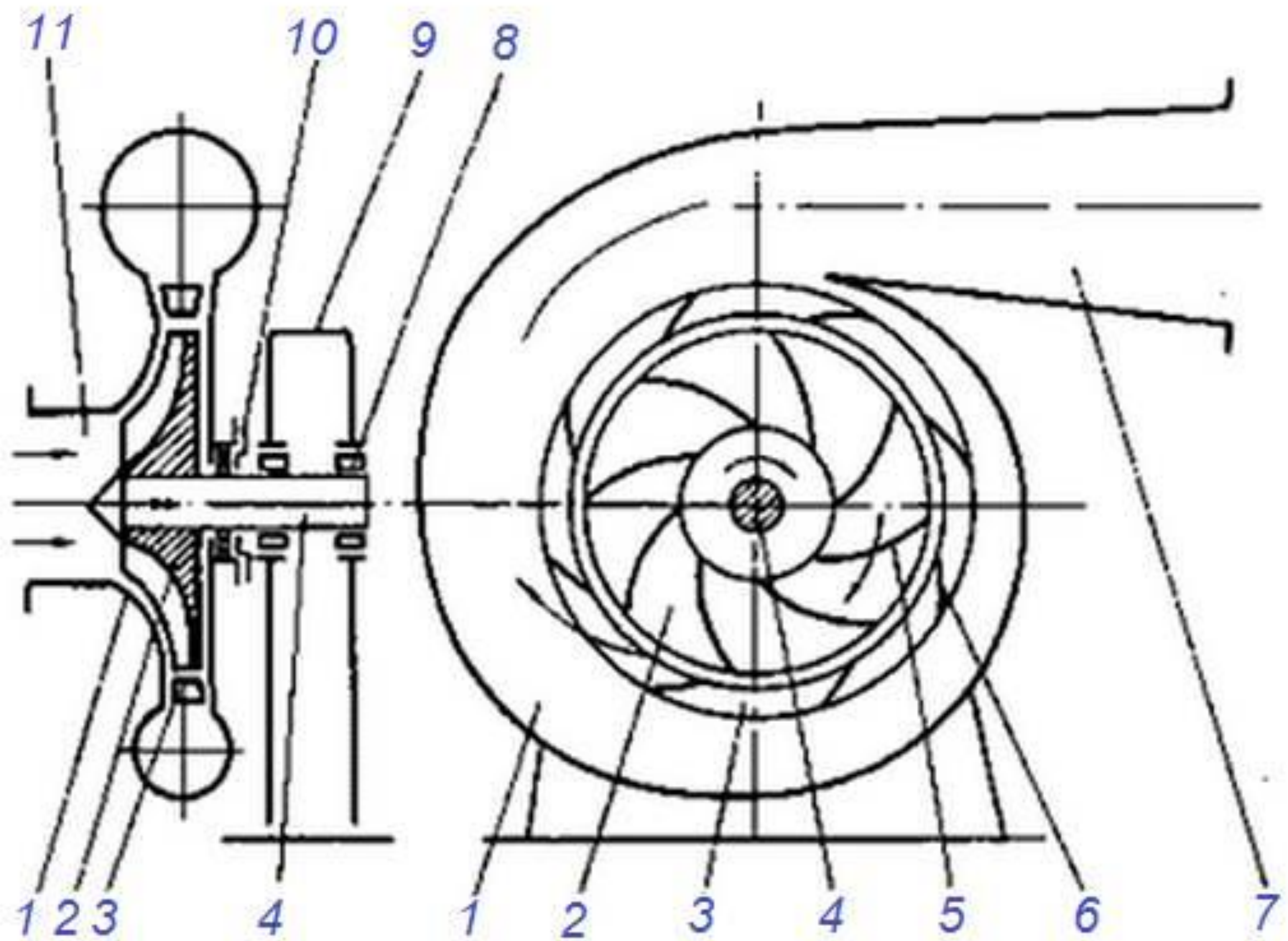


CLASSIFICATION OF PUMPS BY OPERATIONAL PRINCIPLE

- By operation principle the pumps could be divided into dynamic (where liquid is always moved by the hydrodynamic forces) and volumetric (where the pressure is created by decreasing volume of working space). The distinguishing feature is connection between inlet and outlet cross-section: for dynamic it's constant, for volumetric – it appears periodically.
- The dynamic could be further divided into blade-type (where the fluid velocity is increased due to effect of blades) and frictional (where the velocity is increased due to frictional effects).
- The volumetric pumps are usually divided by type of drive: if it is crankshaft – than it's pump of reciprocating type, if rotor – than rotary type.

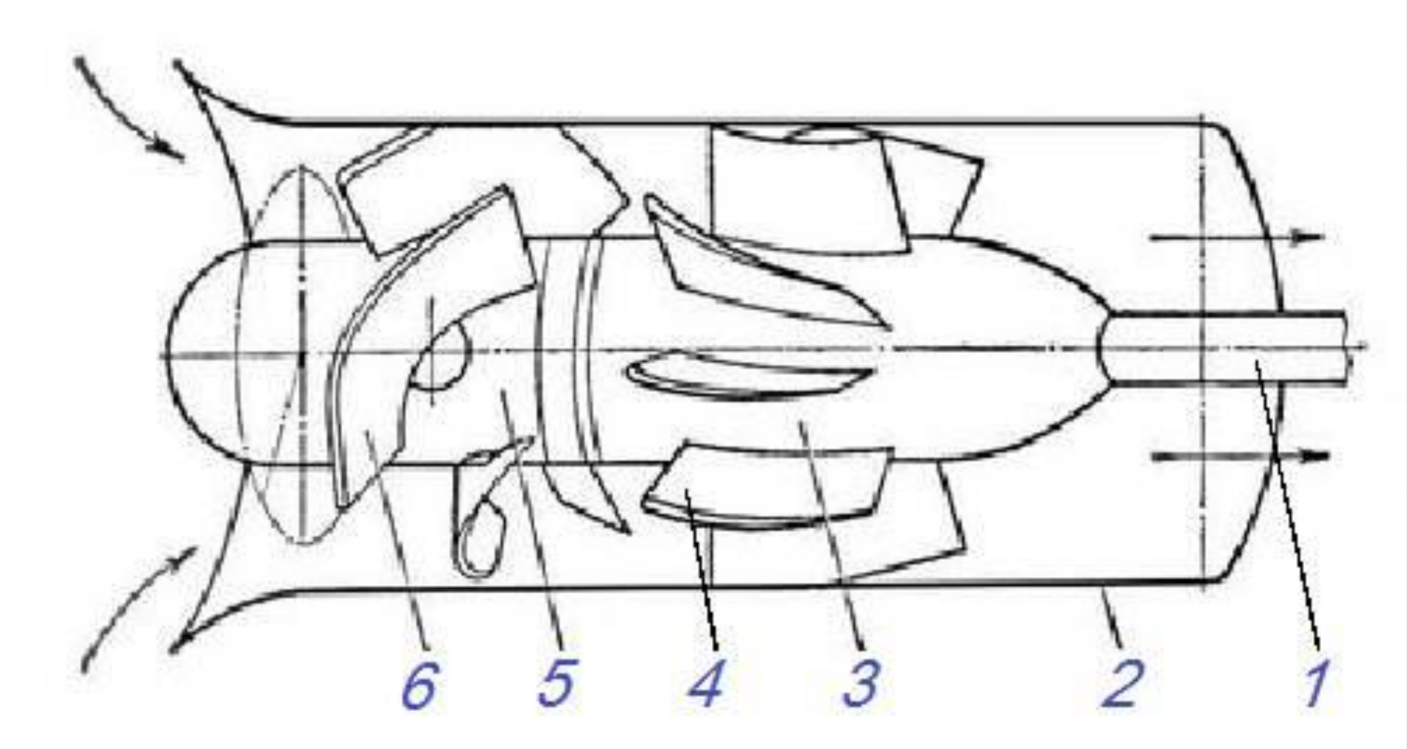
- Majority of pumps on NPP are of dynamic, blade-type.

CONSTRUCTION OF DYNAMIC CENTRIFUGAL BLADE-TYPE PUMP



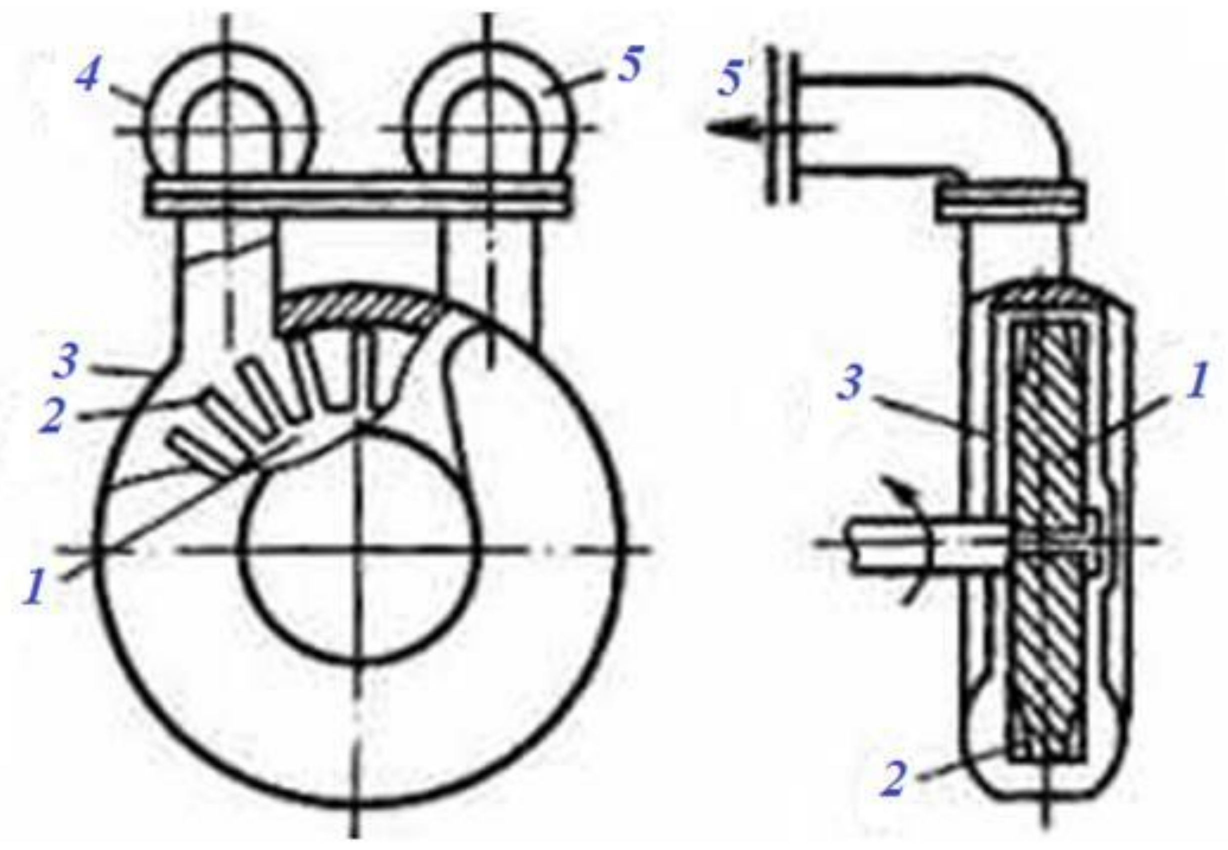
1. Working cavity
2. Working wheel
3. Guiding device
4. Shaft
5. Working wheel blade
6. Guiding device blade
7. Outlet pipeline
8. Bearing
9. Pump casing
10. Hydraulic packing of the shaft
11. Sucking pipeline

CONSTRUCTION OF DYNAMIC AXIAL BLADE-TYPE PUMP



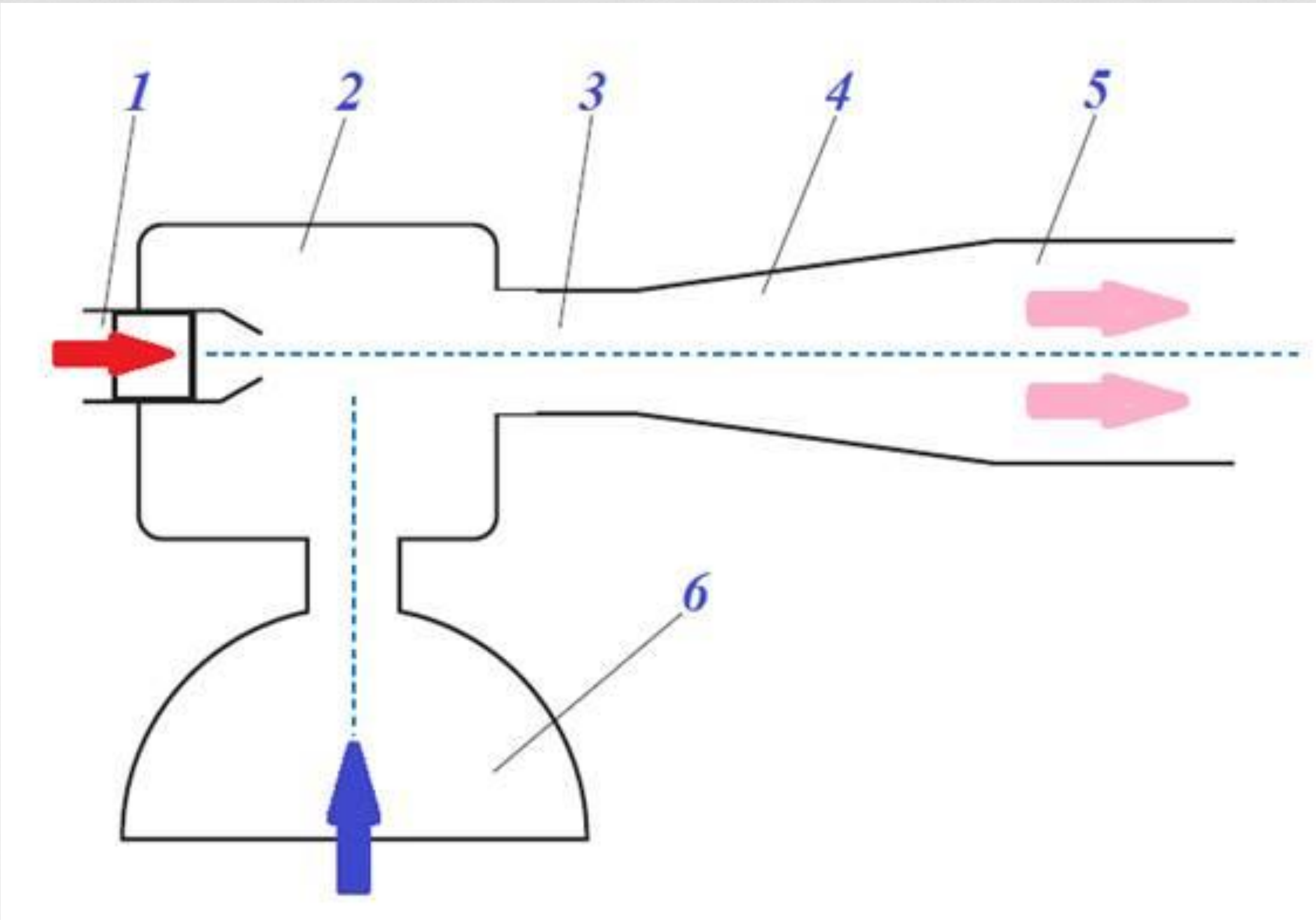
1. Shaft
2. Casing
3. Directing device
4. Directing blades
5. Working wheel
6. Blades of working wheel

CONSTRUCTION OF DYNAMIC FRICTIONAL VORTEX PUMP



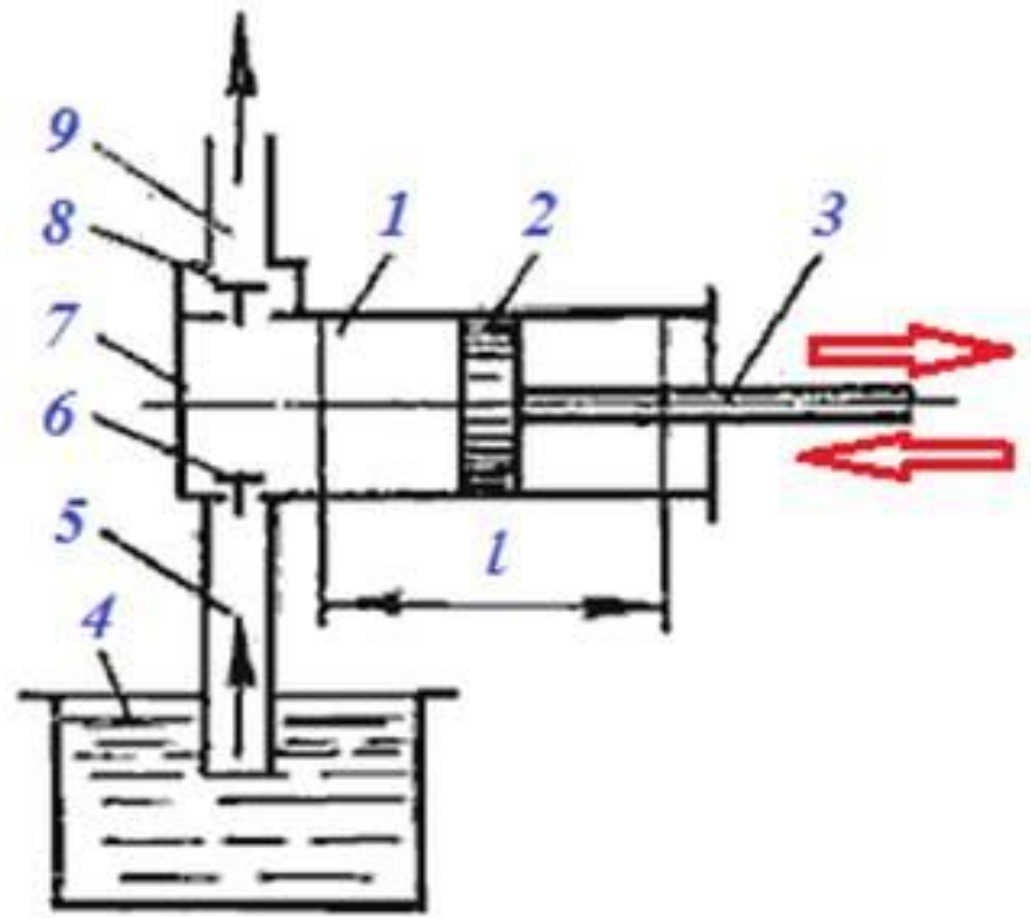
1. Working wheel
2. Blades
3. Casing
4. Inlet pipe
5. Outlet pipe

CONSTRUCTION OF DYNAMIC FRICTIONAL JET-TYPE PUMP



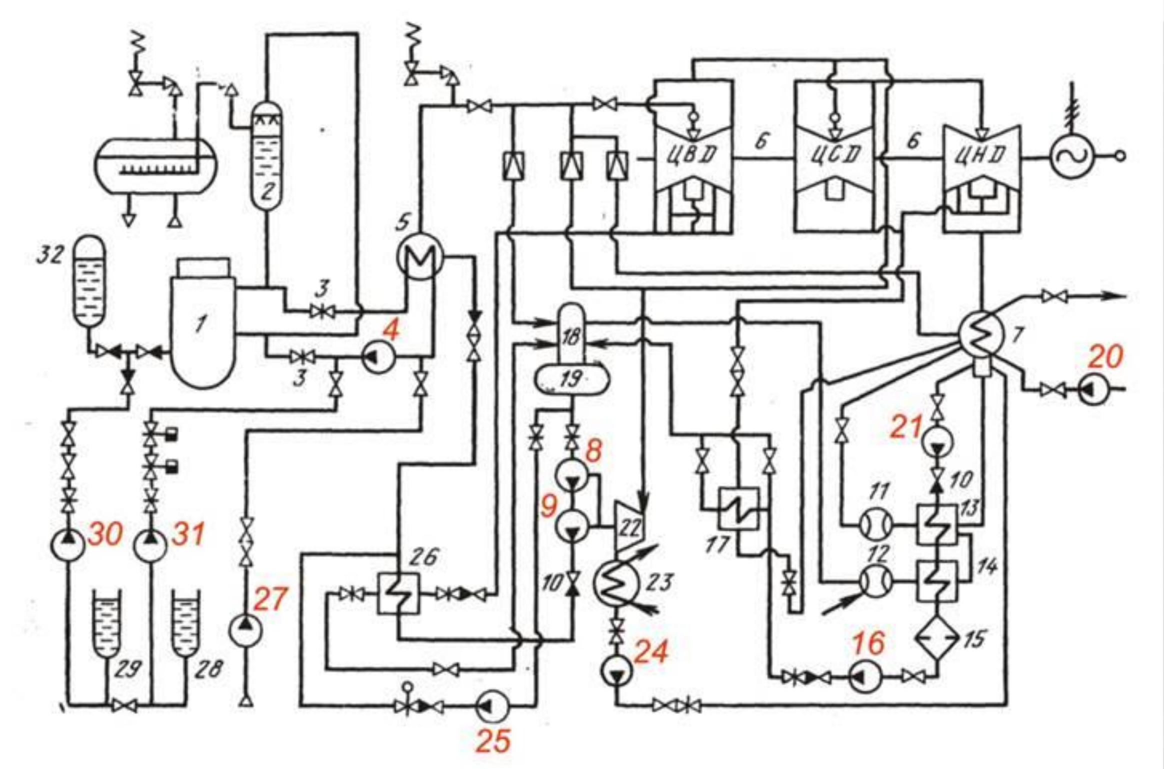
1. Inlet nozzle
2. Mixing chamber
3. Cylindrical chamber
4. Diffusor
5. Outlet pipeline
6. Receiving vessel

CONSTRUCTION OF VOLUMETRIC PISTON-TYPE PUMP



1. Cylinder
2. Piston
3. Shaft
4. Inlet vessel
5. Outlet vessel
6. Inlet valve
7. Pressure chamber
8. Outlet valve
9. Outlet pipe

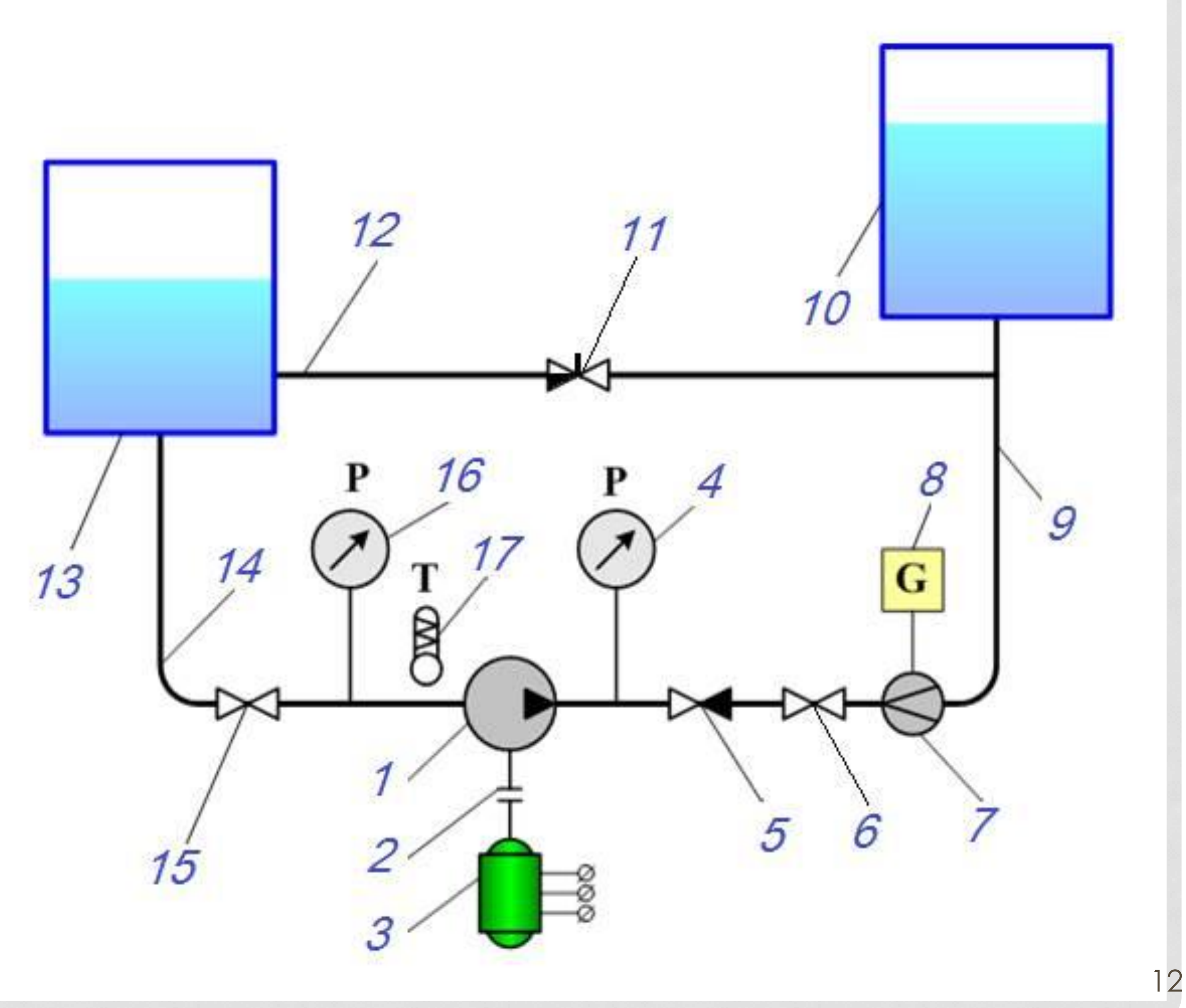
CLASSIFICATION OF PUMPS BY PLACE IN THERMAL SCHEME OF NPP



1. Main circulation pumps
2. Condensate pumps
3. Feedwater pumps
4. Circulation pumps
    1. Cooling water pumps
    2. Additional pumps
5. Network pumps

CONTENT OF PUMP UNIT

1. Pump
2. Coupling
3. Drive
4. Manometer
5. Back-pressure valve
6. Valve
7. Diaphragm
8. Flow rate meter
9. Outlet pipeline
10. Outlet vessel
11. Control valve
12. Recirculation line
13. Inlet valve
14. Inlet pipeline
15. Valve
16. Manovacumeter
17. Thermometer



MAIN CHARACTERISTICS OF THE PUMPS

- The most important characteristics of the pumps are:
  - Head *H* or pressure *Δp*;
  - Capacity Q *(**volumetric** or mass capacity)*;
  - Efficiency *η*;
  - Power *N;*
  - Cavitation margin h_c.

All of these characteristics are determined by pump construction.

- <u>Head</u> – the pressure difference between inlet and outlet of the pump expressed into m of water column or Pa.
- Usually head is expressed in units of pressure (Pa) and meters of water column (m). Correlation between these two units could be obtained using hydrostatic pressure equation:

$$\Delta p=\rho g H$$

here H – head of pump, m; ρ – density of water, kg/m^3; g – gravitational acceleration, m/s^2.

MAIN CHARACTERISTICS OF THE PUMPS

- Pump capacity (volumetric flow rate) – volume of the water pumped through the equipment per unit of time. Measured in m^3/s.

- Efficiency – relation between obtained from grid energy and energy which was spent on the pumping of the water. Measured in % (or unitless).
- There are three major types of efficiencies:
  - Hydrodynamic (η_{hyd}) – takes into account hydraulic losses.
  - Volumetric (η_{vol}) – takes into account both internal (recirculation) and external leakages.
  - Electro-mechanical (η_{mech}) – takes into account mechanical losses during transition of torque from drive and electrical efficiency of drive itself.

HYDRODYNAMIC EFFICIENCY

- Hydraulic losses into pumps is caused by friction due to friction of flow and vortex-formation.
- Hydrodynamic efficiency could be defined as:

$$\eta_{hyd} = H / \left(H + h\right) = \left(H_T + h\right) / H_T = 1 - h / H_T$$

here H – head of pump, m; H_T – theoretical head of pump, m; h – head losses, m.

- Hydraulic efficiency depend on:
  - Form of pump inner cavity (amount of turns and curves);
  - Roughness of internal surfaces;
  - Viscosity of fluid.

Hydraulic efficiency of actual modern pumps lays in range 80-96 %.

VOLUMETRIC EFFICIENCY

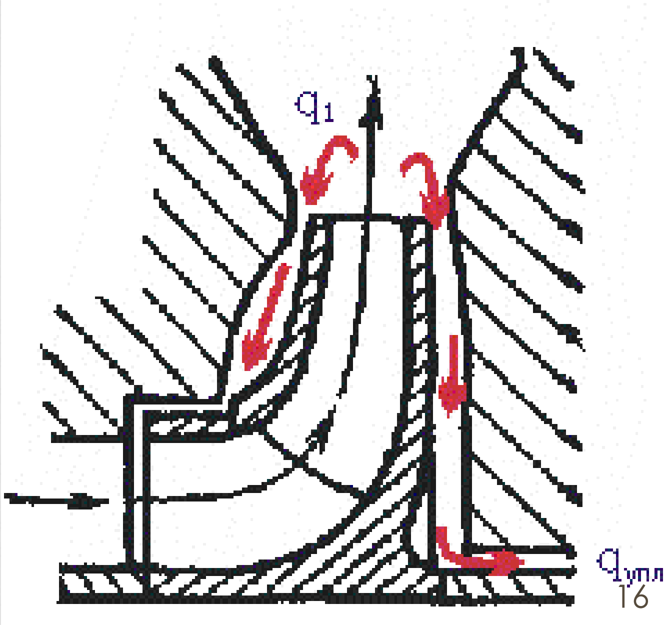
- Volumetric losses of fluid is majorly caused by fluid leakages:
  - From outlet of wheel to its inlet – q1;
  - From one stage to another (in case of multistage compression) – q2;
  - Into hydraulic axial force compensator – q3;
  - Into shart-end seal (*the only leakages to the outside*) – q_l .
- Volumetric efficiency could be defined as:

$$\eta_{vol} = Q / (Q + \Delta Q) = 1 / (1 + k_{loss})$$

here Q – volumetric capacity of pump, m^3/s; ΔQ – fluid losses flow rate, m^3/s; $k_{loss} = \Delta Q / Q$ – leakage coefficient.

Volumetric efficiency depend on sealings type and radial gap.

Volumetric efficiency of actual modern pumps lays in range 96-98 %.



INTERNAL AND MECHANICAL EFFICIENCY

- Hydrodynamic and volumetric efficiency combined is called internal efficiency of pump characterizing perfectness of pump itself:

$$\eta_{int} = \frac{N}{N_{in}} = \frac{\rho \cdot g \cdot Q \cdot H}{\rho \cdot g \cdot (Q + \Delta Q) \cdot (H + \Delta H)} = \eta_{hyd} \cdot \eta_{vol}$$

- Mechanical efficiency takes into account losses due to:
  - Friction in bearings and shaft sealings;
  - Hydraulic friction of external surface of wheel;
  - Sometimes the efficiency of electrical drive is also included.

$$\eta_{mech} = N_{in} / N_{cons}$$

N_{in} – internal power, W; N_{cons} – total consumed power, W.

- Total efficiency – relation between useful and consumed power.

$$\eta_{mech} = \frac{N}{N_{cons}} = \frac{N}{N_{in}} \cdot \frac{N_{in}}{N_{cons}} = \eta_{hyd} \cdot \eta_{vol} \cdot \eta_{mech}$$

MAIN CHARACTERISTICS OF THE PUMPS

- Cavitation – process of steam bubble formation when pressure decreasing below saturation point.
- Formation and collapsing of such bubbles will result into intense erosion of working wheel. In pumps cavitation occurs on the inlet of the first stage when the velocity of the flow increases. In order to prevent such effects the high enough pressure should be ensured on the inlet of pump. Minimal "safe" pressure on the inlet to pump is called cavitation margin. It is usually expressed in units of pressure (Pa) or head (m). In technic it is usually called NPSHr – Net Positive Suction Head Required.
- The most safe and reliable method of cavitation preventing – putting pump below previous reservoir on the value of cavitation head. This fact determines many arrangement solutions of NPP reactor and turbine sites.

CHARACTERISTIC OF THE PUMP

- <u>Power</u> is another important characteristic of pump. Measured in W. But it's derivative from another characteristics of pump:
  - Positively used power:

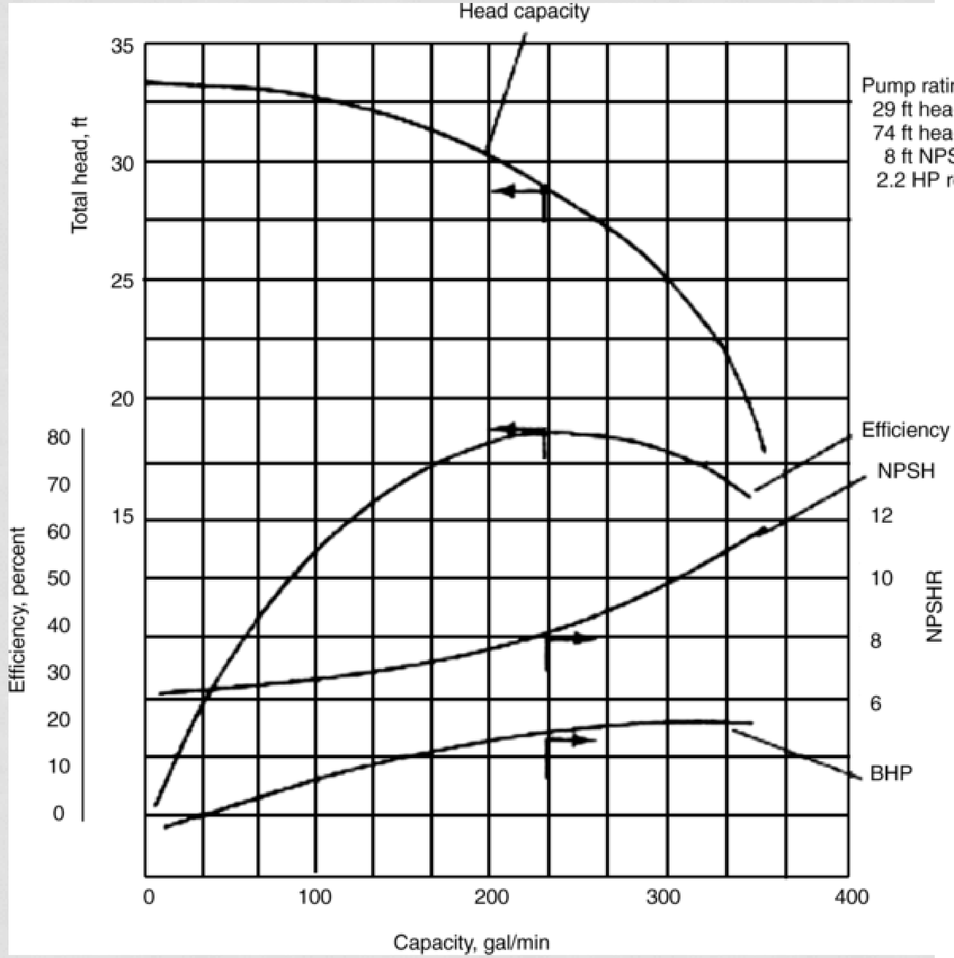
    $$N_p = \Delta p \cdot Q = \rho g H Q$$

  - Consumed power:

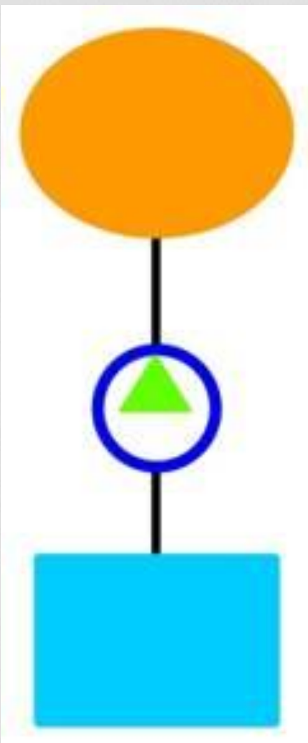
    $$N_c = N_p / \eta_{tot} = \Delta p \cdot Q / \eta_{tot}$$

All characteristics of pump are interconnected and dependent on capacity.

Nominal regime – is the regime where the maximal efficiency is reached.



WORK OF PUMP IN NETWORK



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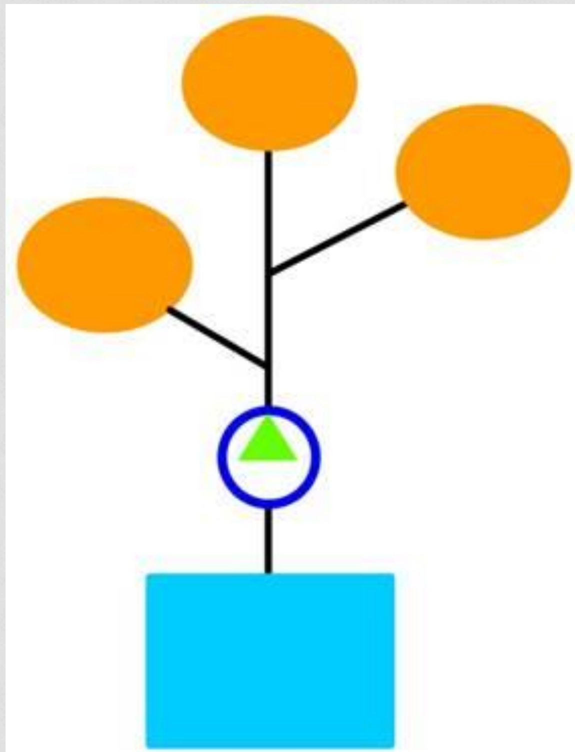

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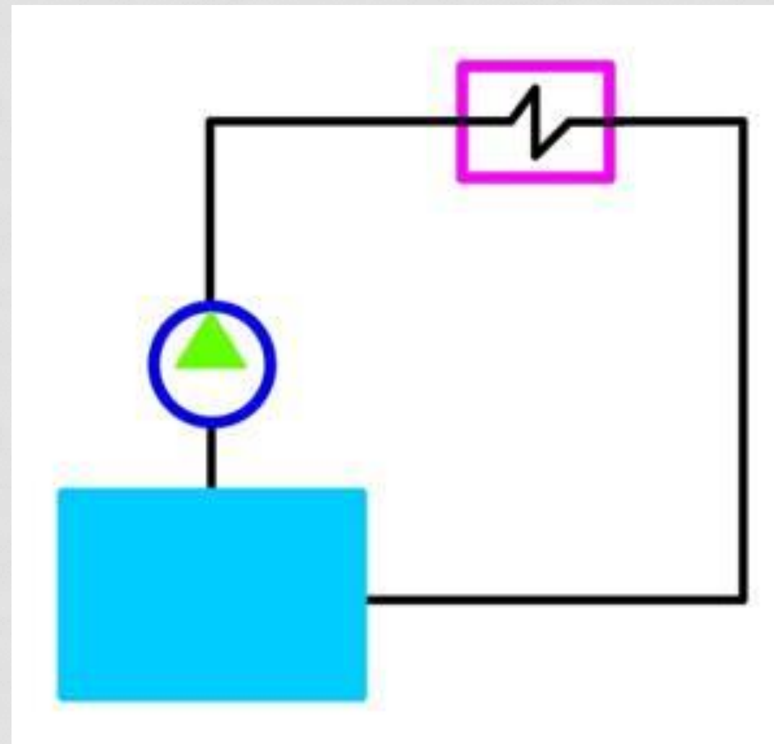


c

Major types of networks

Pump should compensate head and capacity of net,

NEEDED HEAD OF THE PUMP

The pump head is "spent" on:

- Compensation of hydraulic losses in pipeline between pump and consumer Δp_{hyd};
- Increasing of fluid velocity Δp_{vel};
- Increasing of fluid pressure Δp_{pr};
- Lifting of the fluid on the geometrical height Δp_{height};
- Increasing of fluid temperature – considered as losses.

$$\Delta p_{hyd} = \left(\xi_{fr} \cdot \frac{l}{d} + \sum \xi_{loc} \right) \cdot \frac{\rho \cdot w^2}{2} \qquad \Delta p_{vel} = \frac{\rho_{out} \cdot w_{out}^2 - \rho_{in} \cdot w_{in}^2}{2} \qquad \Delta p_{pr} = p_{out} - p_{in}$$

$$\Delta p_{height} = g \cdot \left(\rho_{out} \cdot H_{out} - \rho_{in} \cdot H_{in} \right)$$

$$\Delta p_{pump} = \left(\xi_{fr} \frac{l}{d} + \sum \xi_{loc} \right) \cdot \frac{\overline{\rho}\, \overline{w}^2}{2} + \frac{\rho_{out} w_{out}^2 - \rho_{in} w_{in}^2}{2} + \left(p_{out} - p_{in} \right) + g \left(\rho_{out} \cdot H_{out} - \rho_{in} \cdot H_{in} \right)$$

$$H_{pump} = \left(\xi_{fr} \frac{l}{d} + \sum \xi_{loc} \right) \cdot \frac{\overline{w}^2}{2g} + \frac{w_{out}^2 - w_{in}^2}{2g} + \frac{\left(p_{out} - p_{in} \right)}{\overline{\rho} g} + \left(H_{out} - H_{in} \right)$$

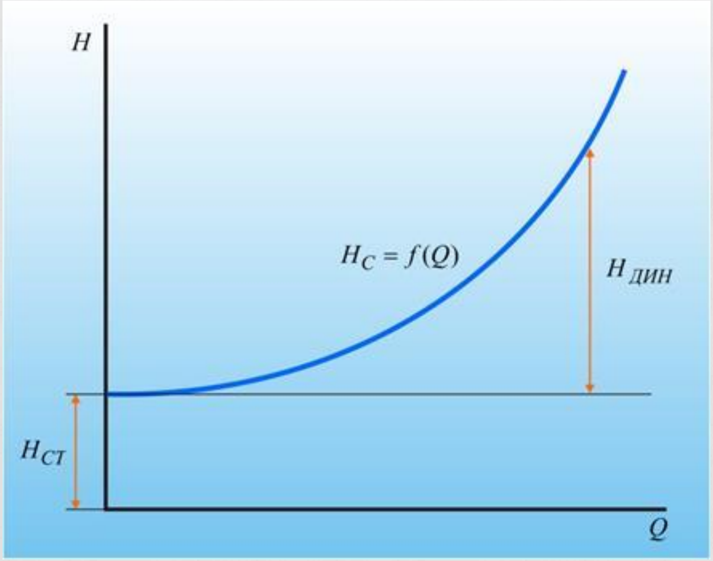
CHARACTERISTIC OF NETWORK

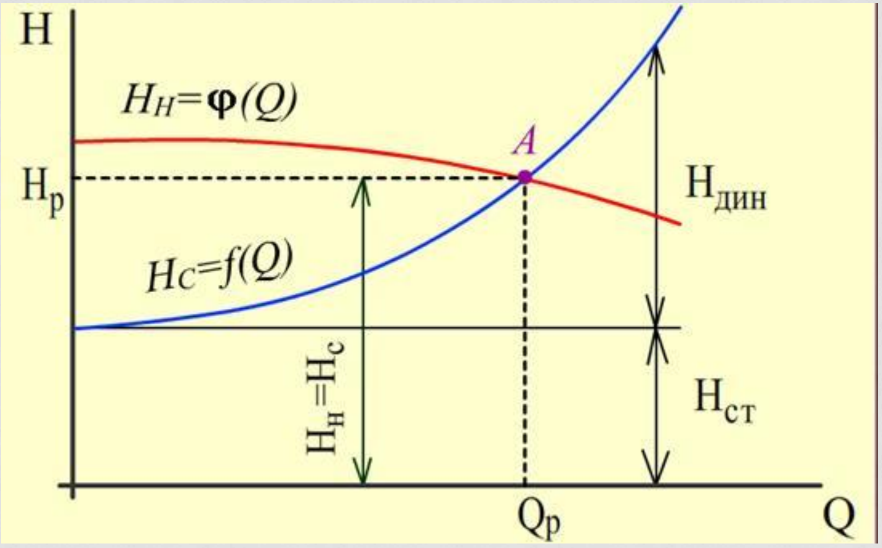
Dependence of pressure losses into network on volumetric flow rate is called characteristic of network:

$$\Delta p=f(Q) \qquad H=f(Q)$$

The two components of network characteristic is determined: static part (independent on flow rate) H_{st} and dynamic part (independent on flow rate) H_{dyn}.

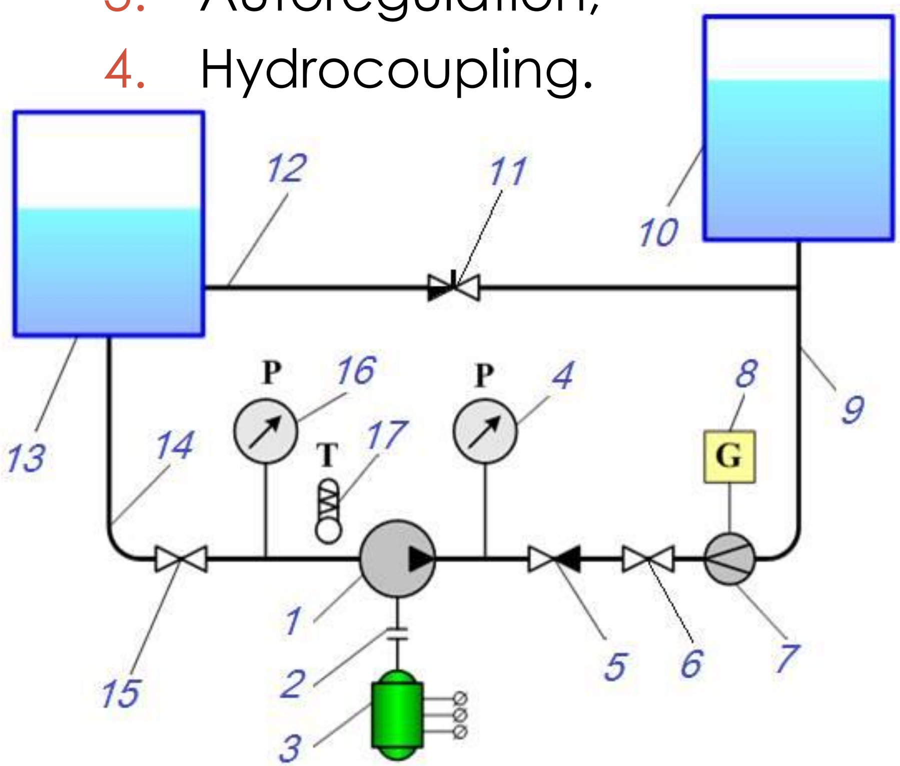
The interception of characteristics of network and actual pump determines actual head and flow rate of pump.





REGULATION OF THE PUMP

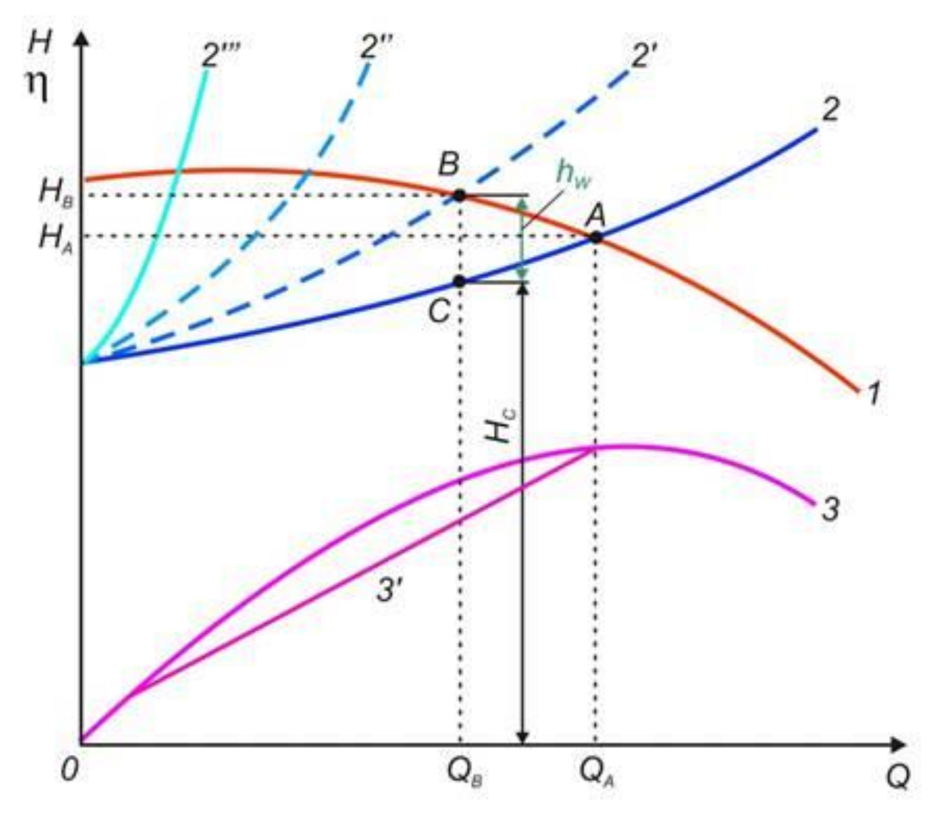
1. Qualitative regulation:
    1. Throttling;
    2. Bypassing;
    3. Autoregulation;
    4. Hydrocoupling.
2. Quantitive regulation:
    1. Drive frequency adjustment;
    2. Change of wheel diameter;
    3. Adjustment of blades incline:
        1. For all blades;
        2. For directional device:
            1. On inlet;
            2. On outlet.



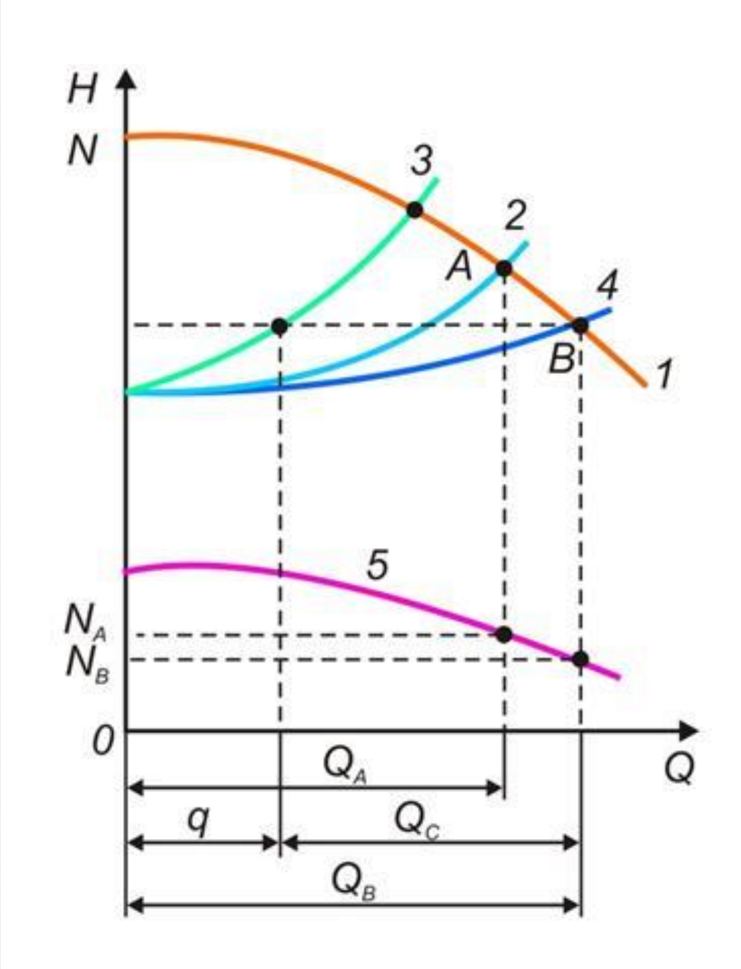
$$H = H_{st} + k \cdot Q^2$$

REGULATION OF THE PUMP

Throttling

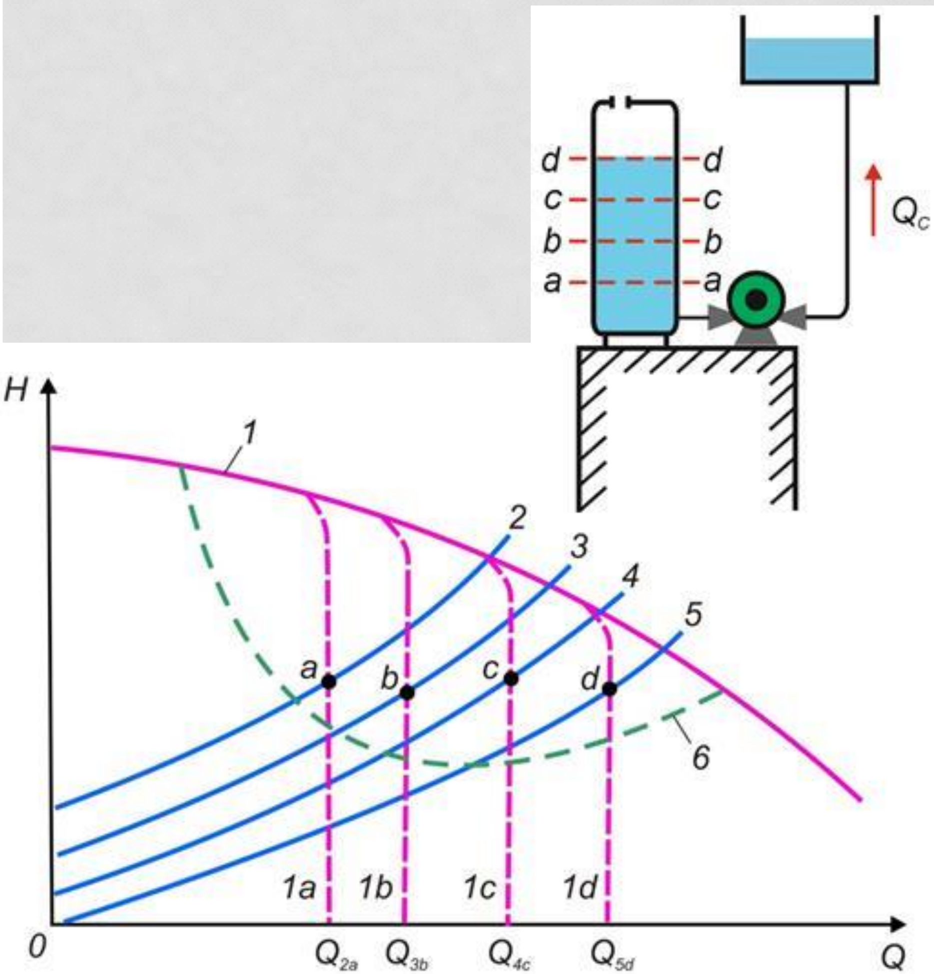


Bypassing

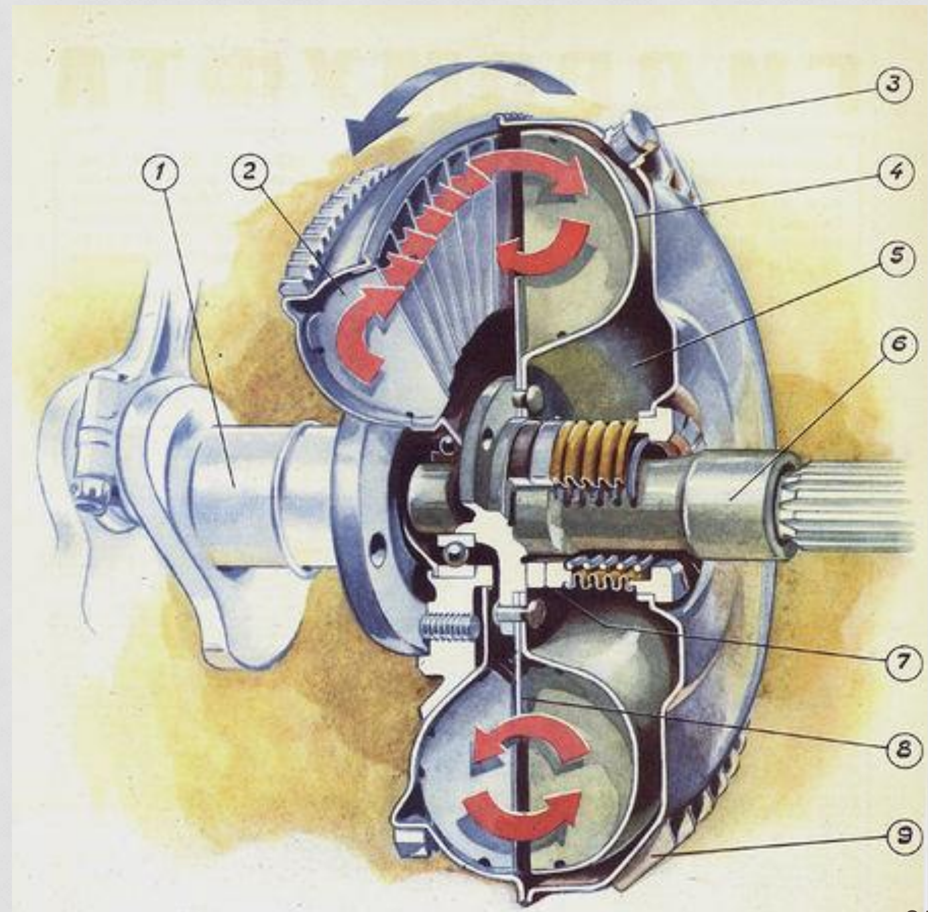


REGULATION OF THE PUMP

Self-regulation

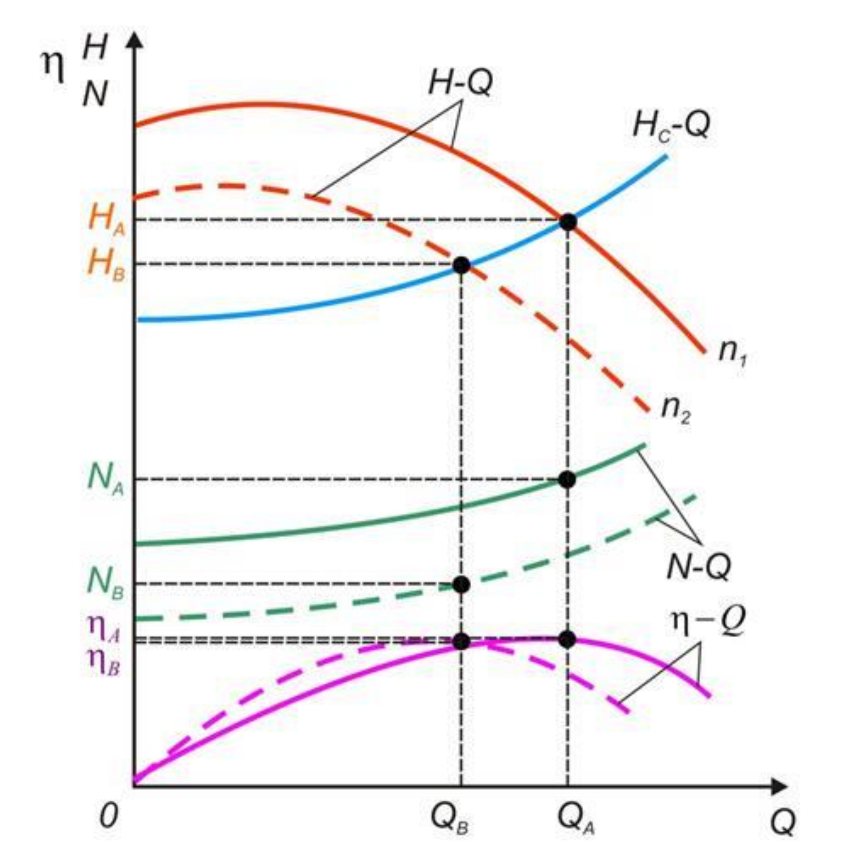


Hydrocoupling



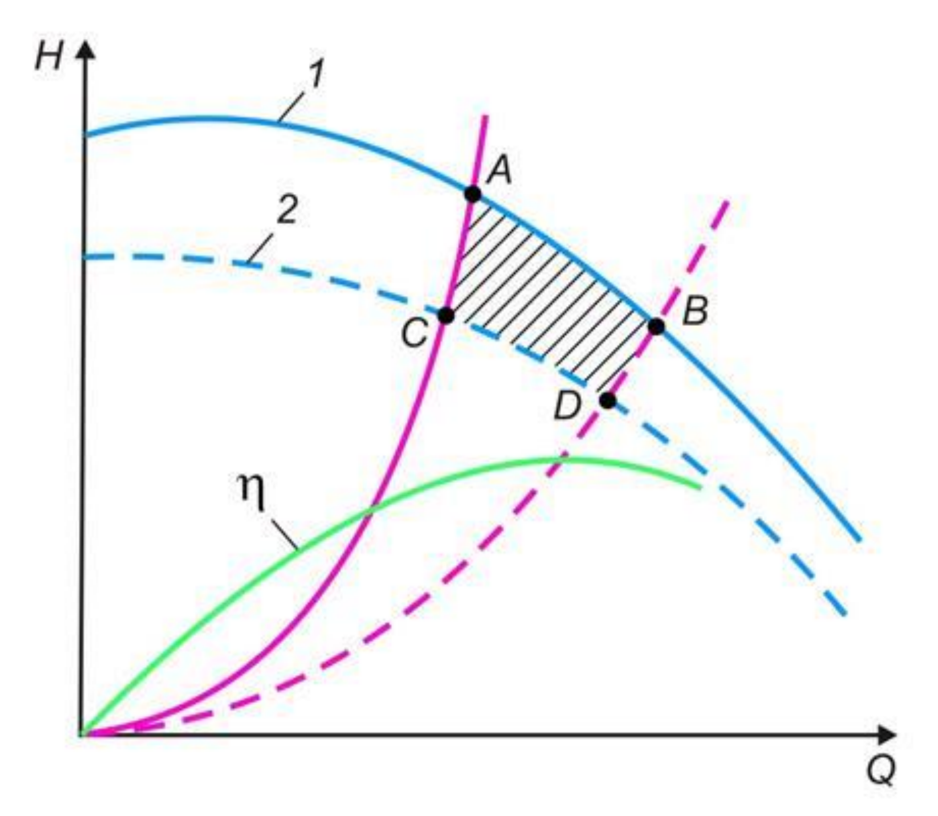
REGULATION OF THE PUMP

Drive frequency adjustment



$$\frac{Q}{Q_0}=\frac{n}{n_0} \quad \frac{H}{H_0}=\left(\frac{n}{n_0}\right)^2 \quad \frac{N}{N_0}=\left(\frac{n}{n_0}\right)^3$$

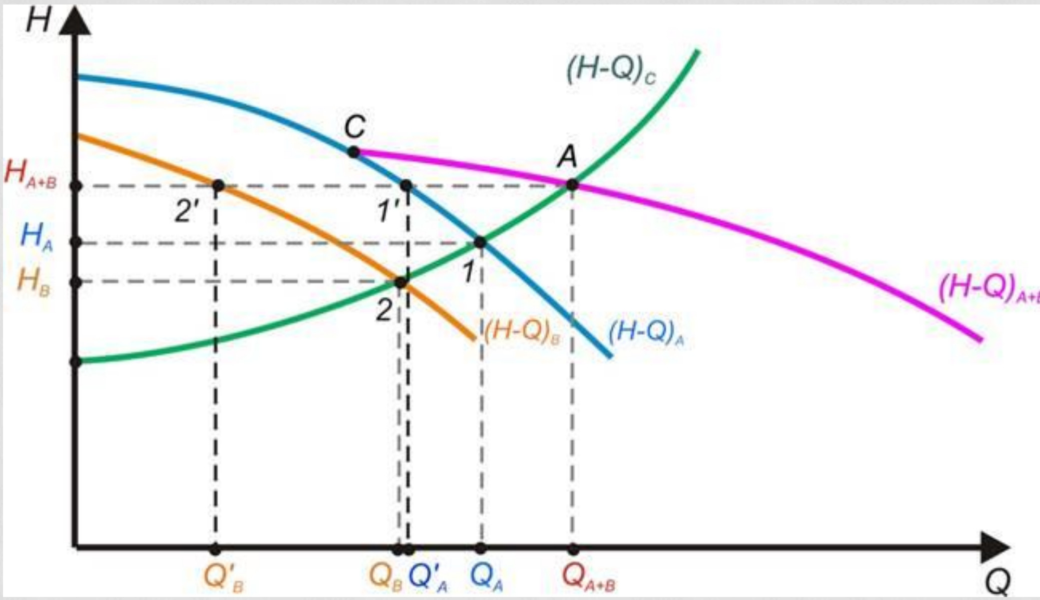
Change of wheel diameter



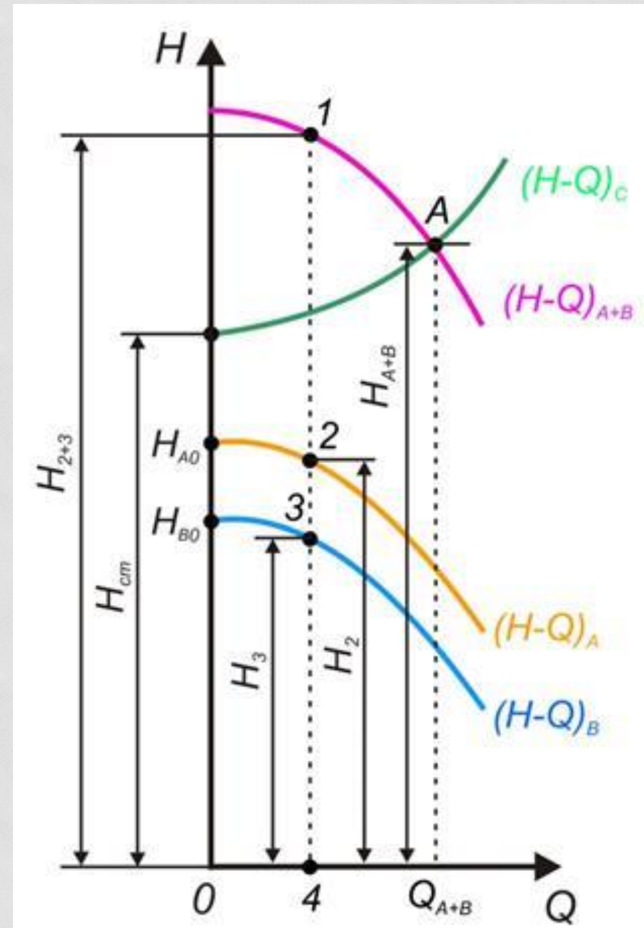
$$\frac{Q}{Q_0}=\frac{D}{D_0} \quad \frac{H}{H_0}=\left(\frac{D}{D_0}\right)^2 \quad \frac{N}{N_0}=\left(\frac{D}{D_0}\right)^3$$

SIMULTANEOUS WORK OF PUMPS

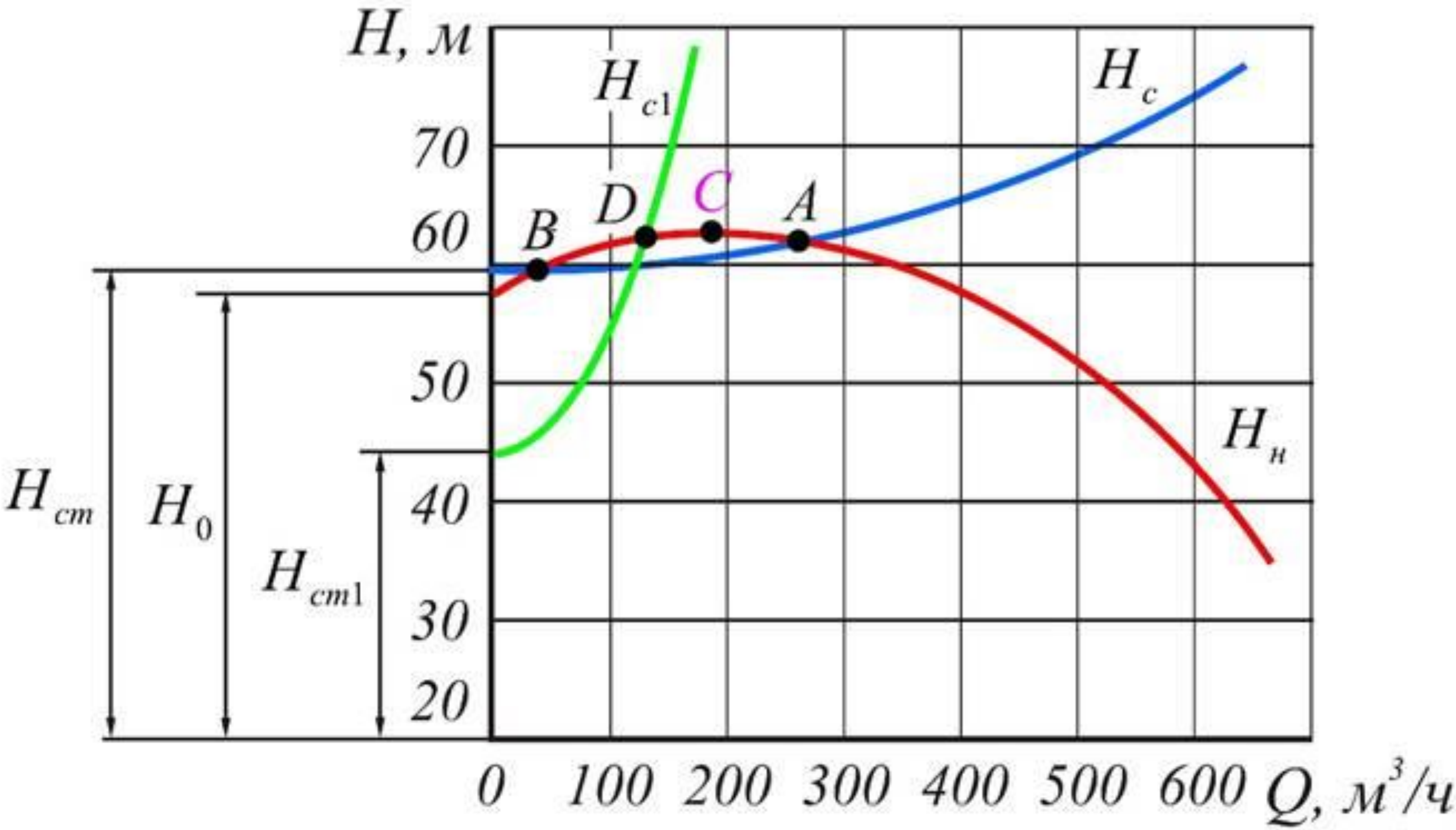
Parallel connection of pumps



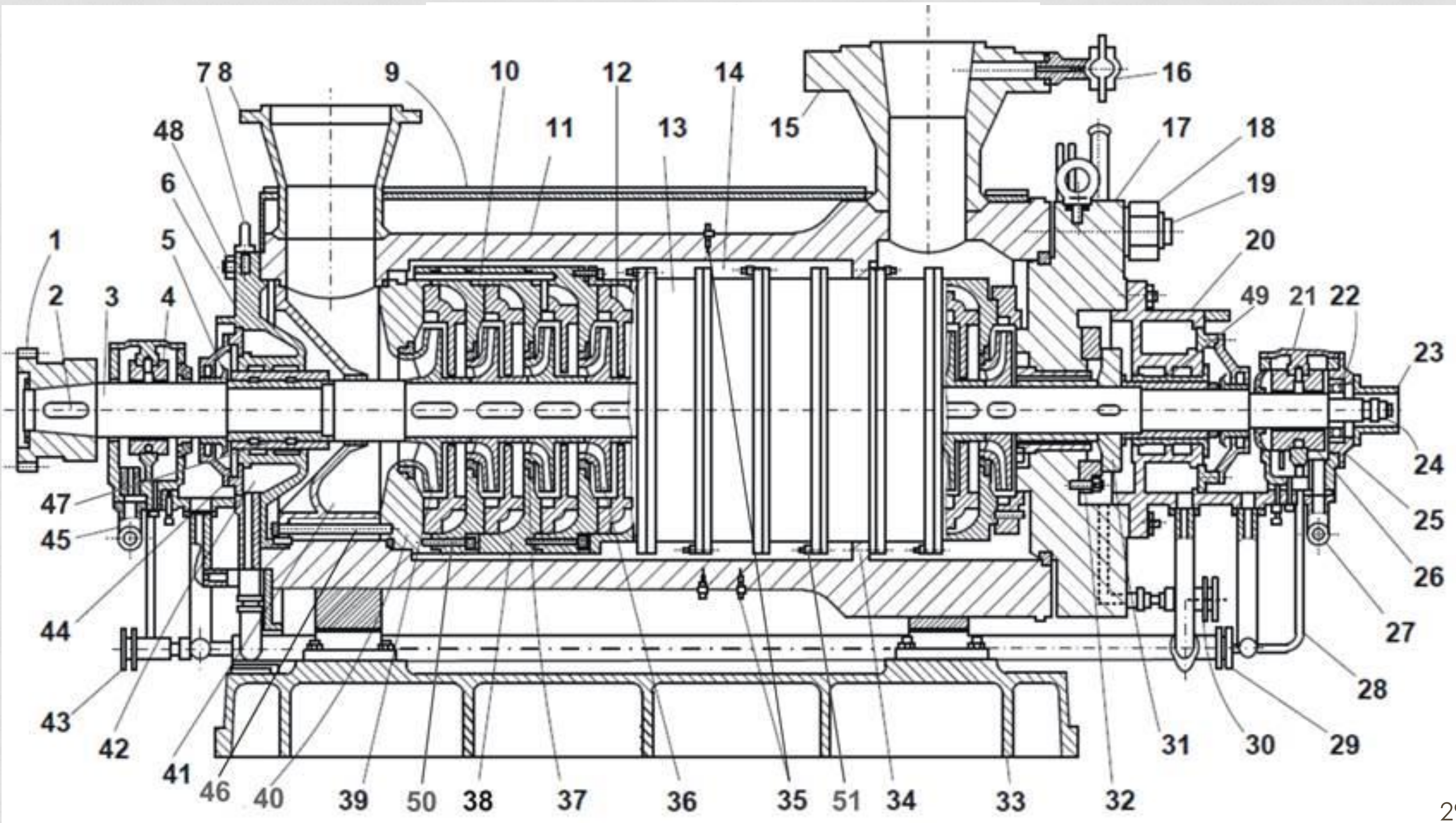
Consequtive connection of pumps



STABLE AND UNSTABLE OPERATION OF PUMP



CONDENSATE PUMP



THANKS FOR ATTENTION