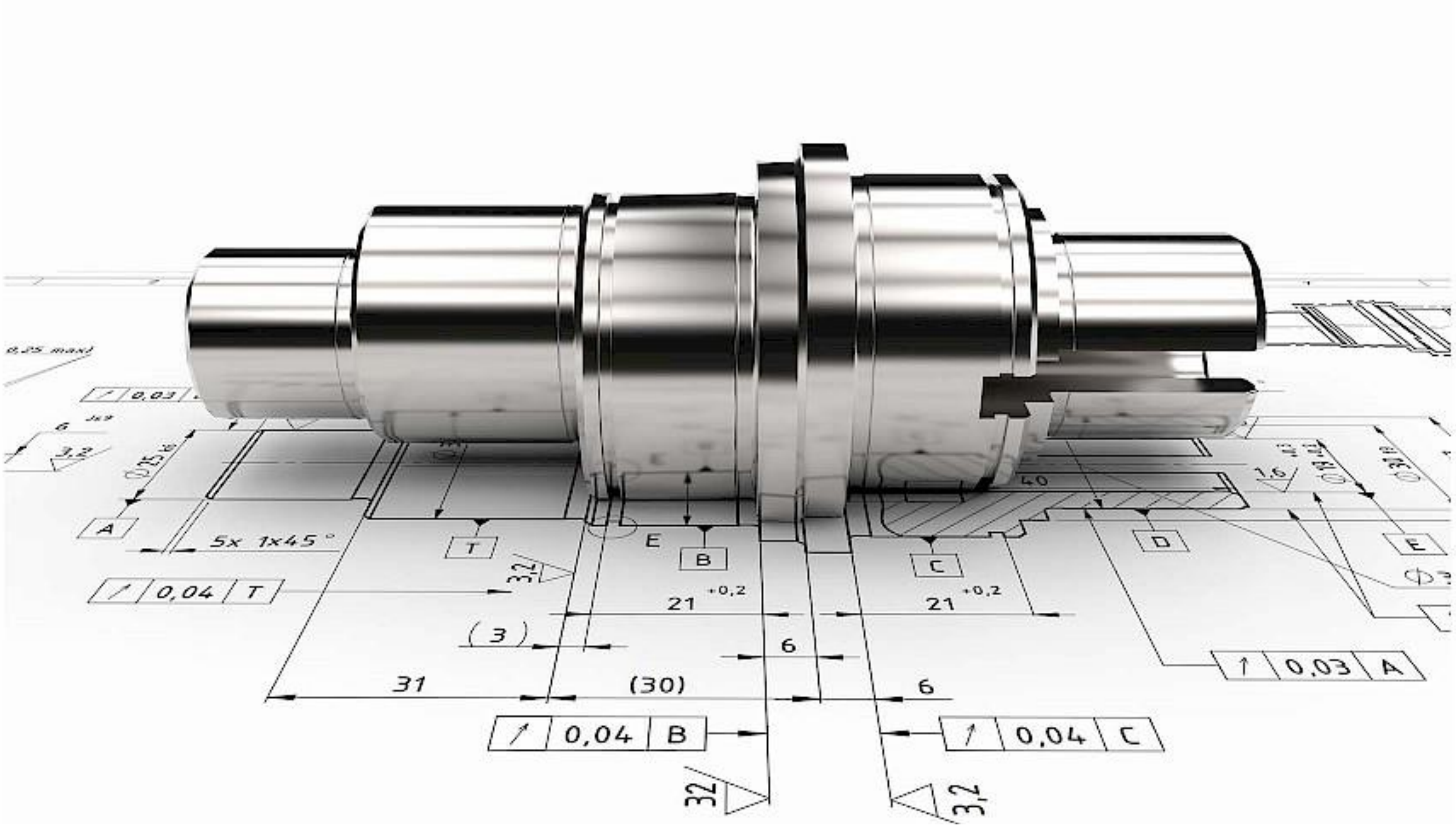
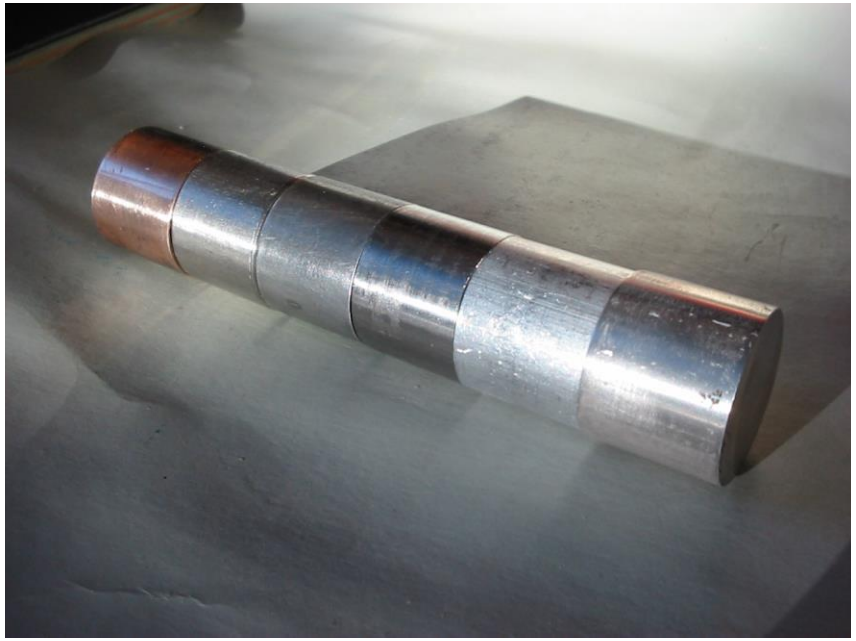
Shafts, axels_2



MATERIALS

Material requirements:

- high fatigue strength (the ability to withstand alternating loads),
- rigidity (have a high modulus of elasticity),
- good machinability of material (geometrical features such as grooves, holes, threads, and keyways may need to be machined)



Low- to medium-carbon and alloy steels meet these requirements most fully.

SHAFTS DESIGN

Shafts may be calculated for:

- **Strength;**
- **Stiffness;**
- **Natural frequency.**

STRENGTH

Calculation of shafts for strength is divided into 3 stages:

- **Minimum diameter of the shaft;**
- **Shaft construction;**
- **Strength analysis**.

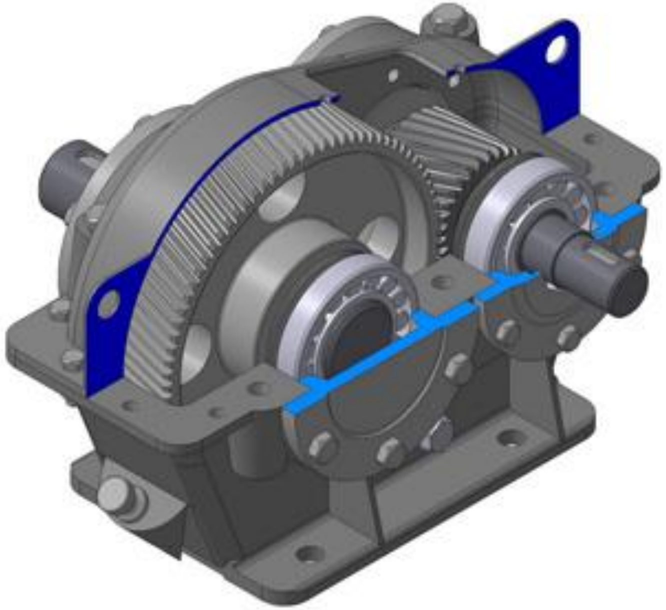
MINIMUM DIAMETER OF THE SHAFT

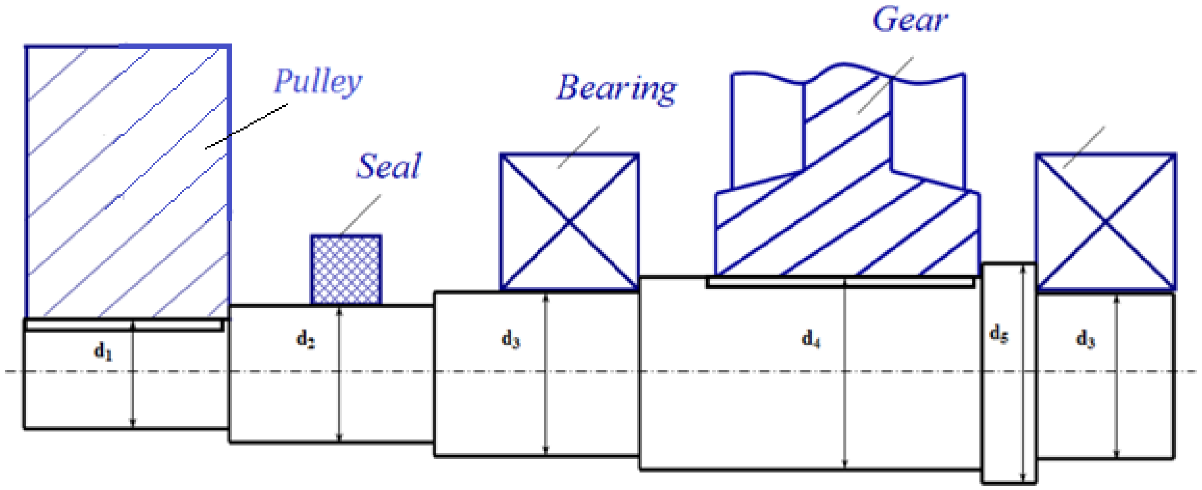
Minimum diameter of the shaft is determined taking into account torsion stresses only. In order to compensate neglect of bending stresses the allowable torsion stress is assumed as down rated ([τ]=15…30 MPa).

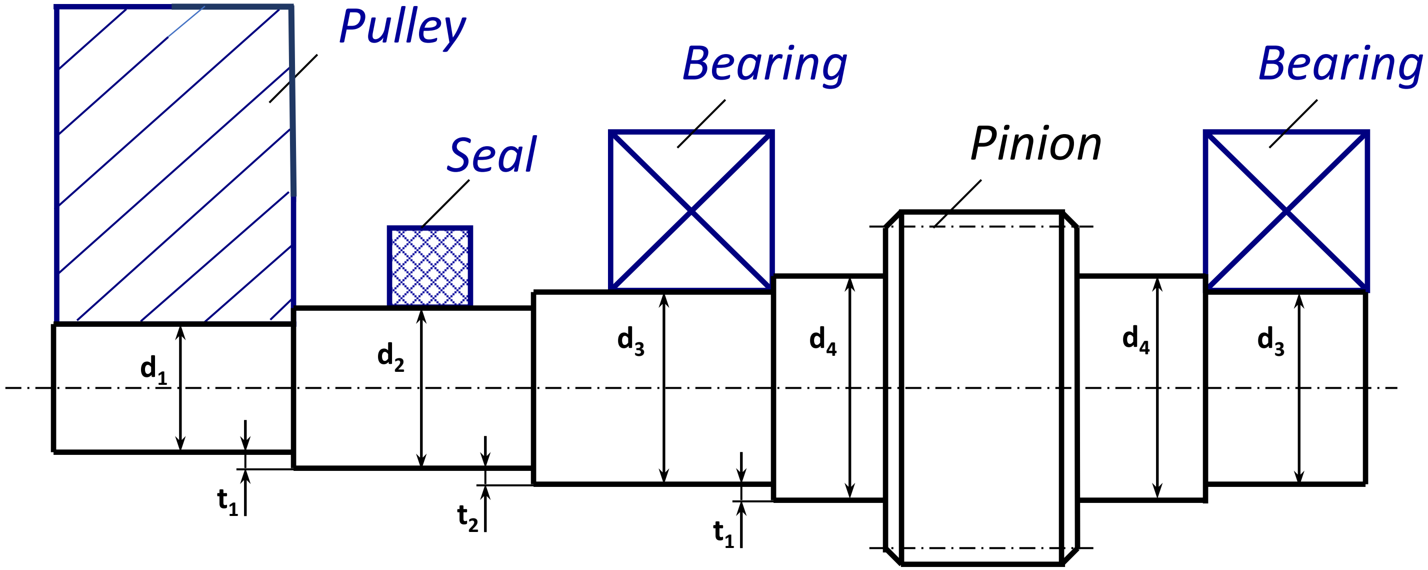
$$\tau = \frac{T}{W_p}; \qquad W_p = \frac{\pi \cdot d^3}{16}.$$

$$d_{min} = \sqrt[3]{\frac{T}{0.2 \cdot [\tau]}}.$$

SHAFT CONSTRUCTION







$$d_1 = d_{min};$$

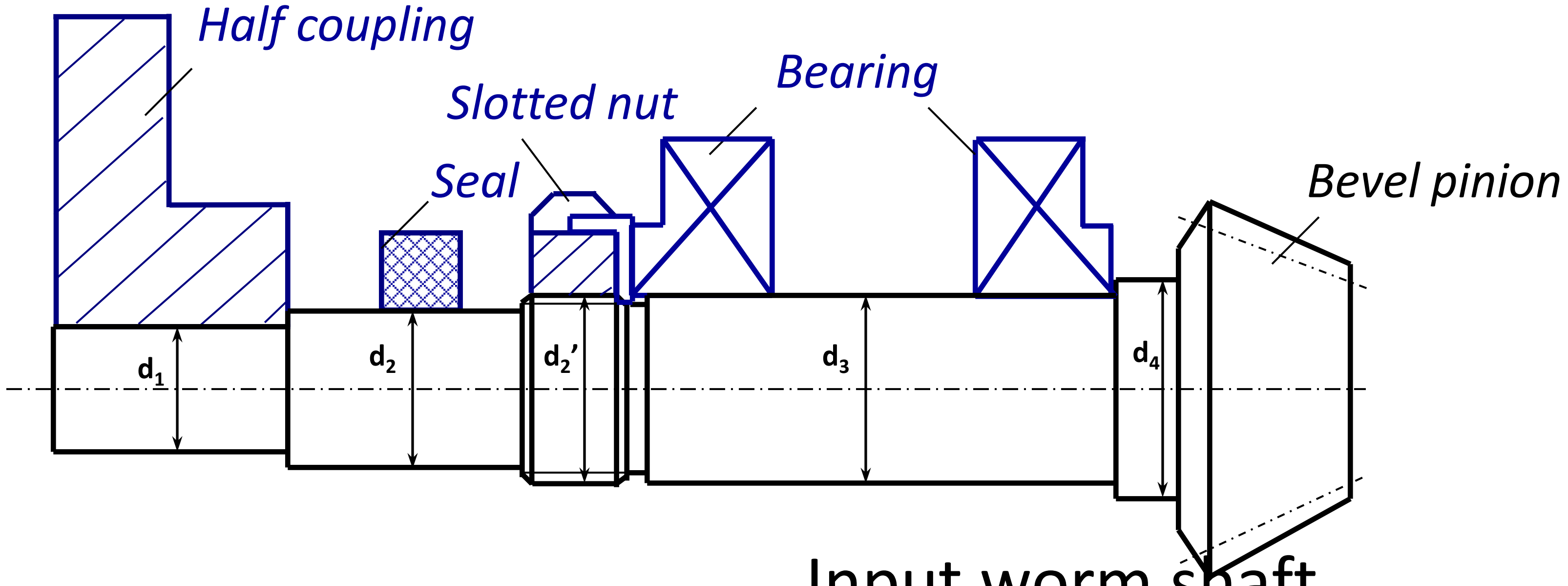
$$d_2 = d_1 + 2 \cdot t_1;$$

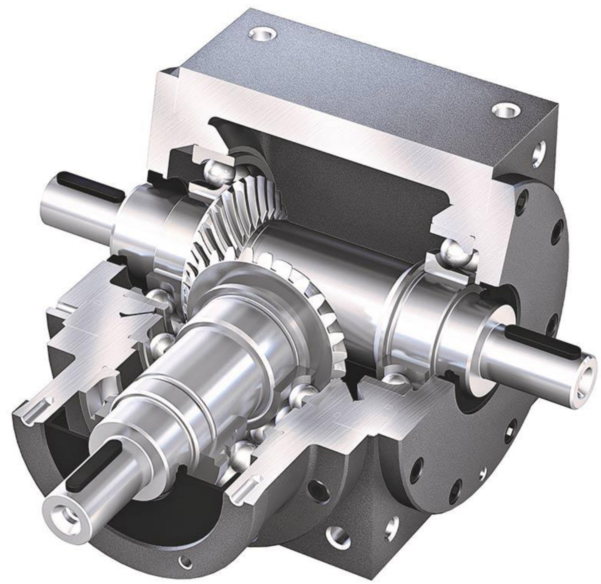
$$d_3 = d_2 + 2 \cdot t_2;$$

$$d_4 = d_3 + 2 \cdot t_1.$$

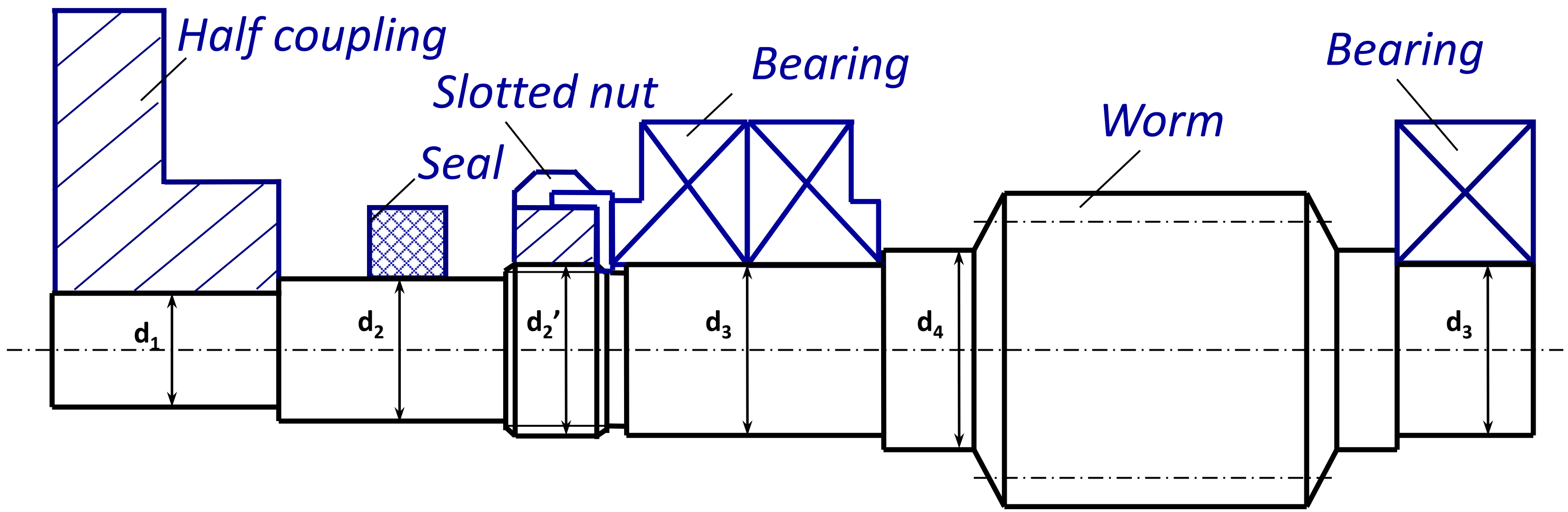
d, *mm*	20…50	55…120
t_1, *mm*	2; 2.5	5
t_2, *mm*	1; 1.5	2.5

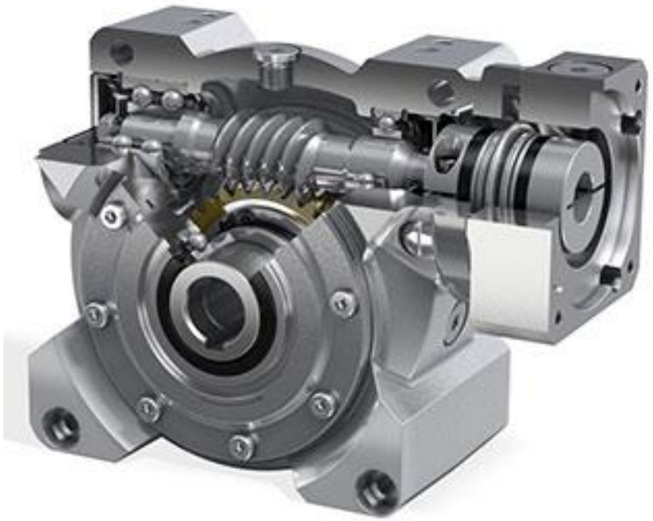
Input bevel pinion shaft



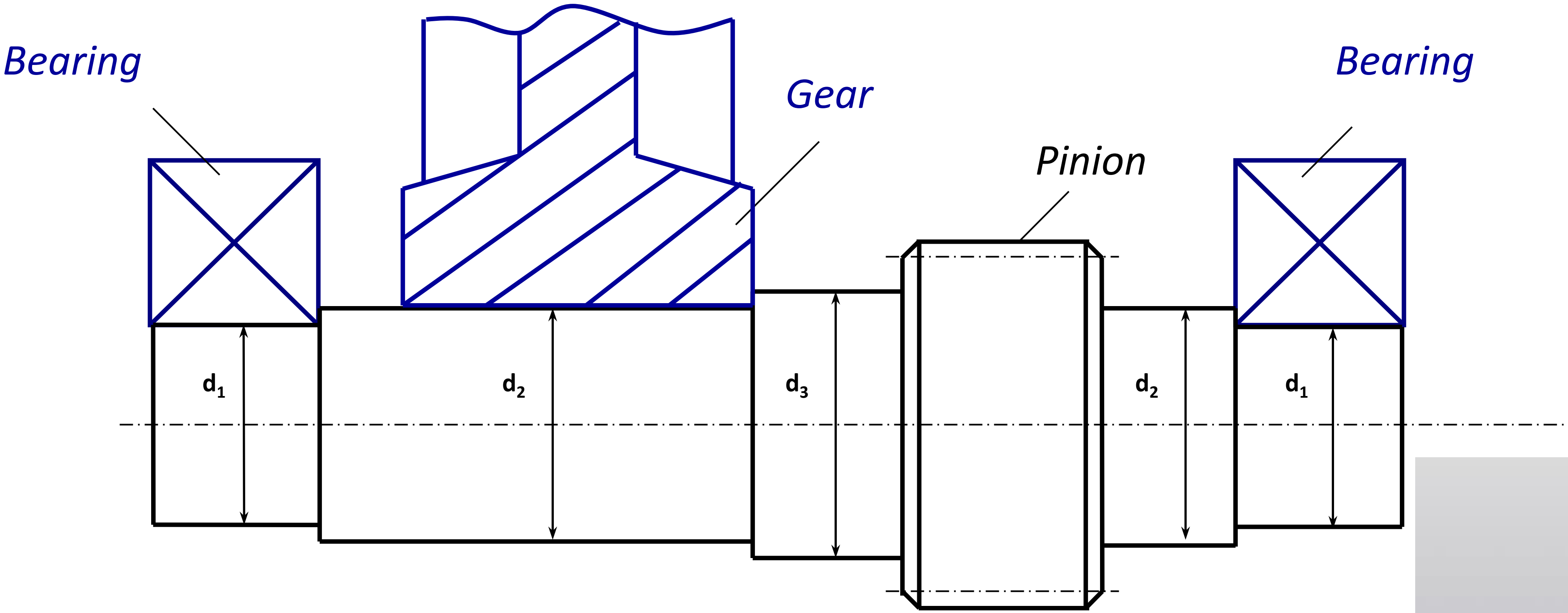


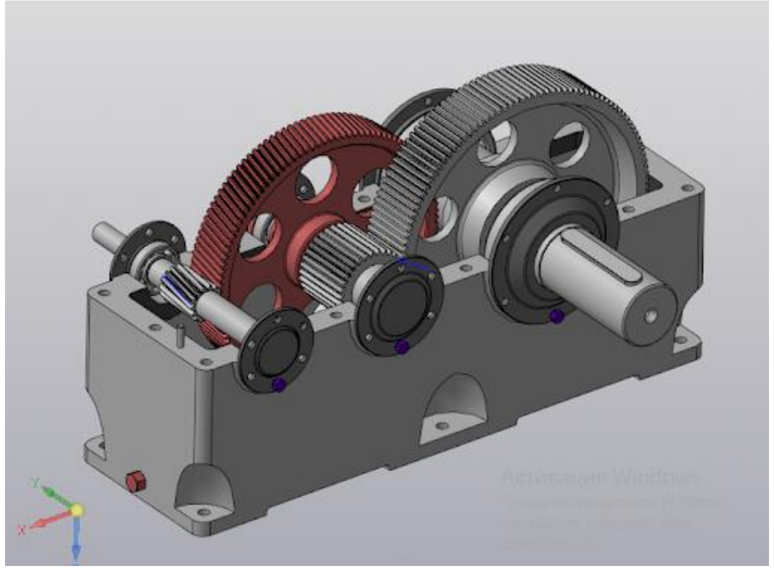
Input worm shaft



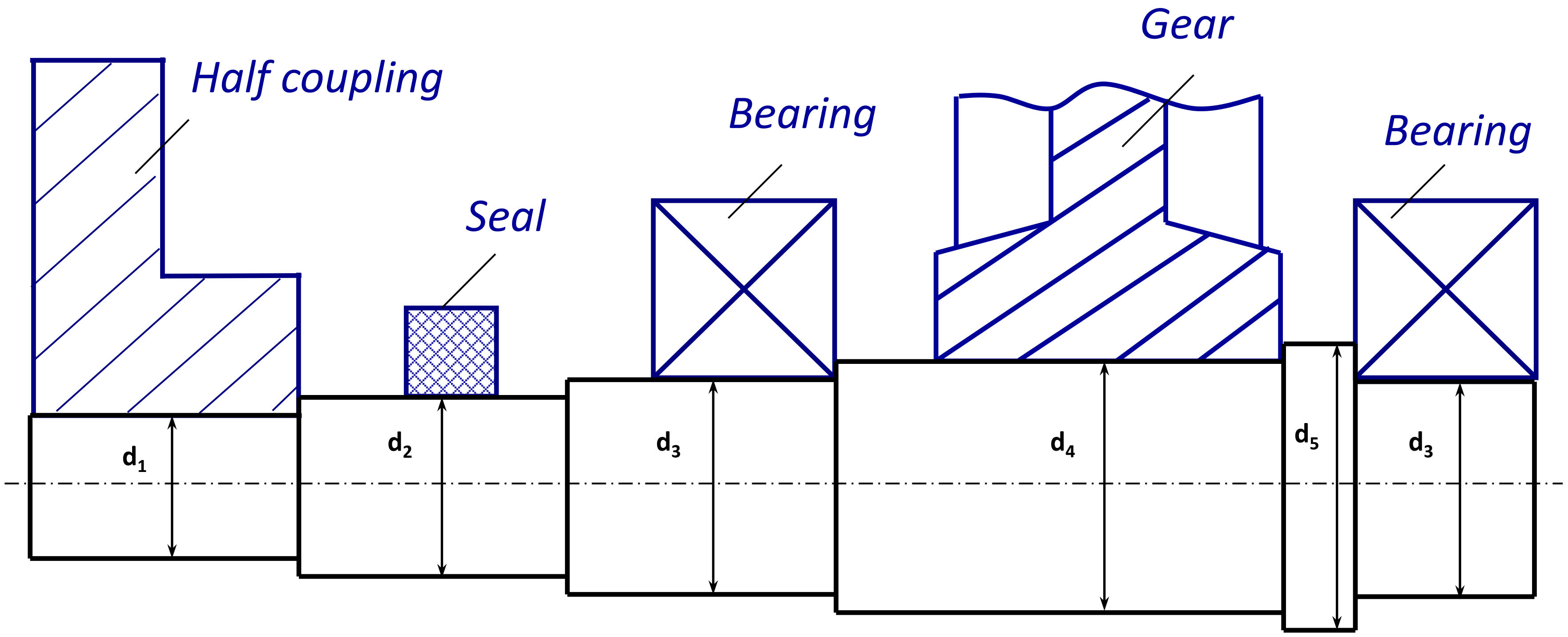


Intermediate shaft

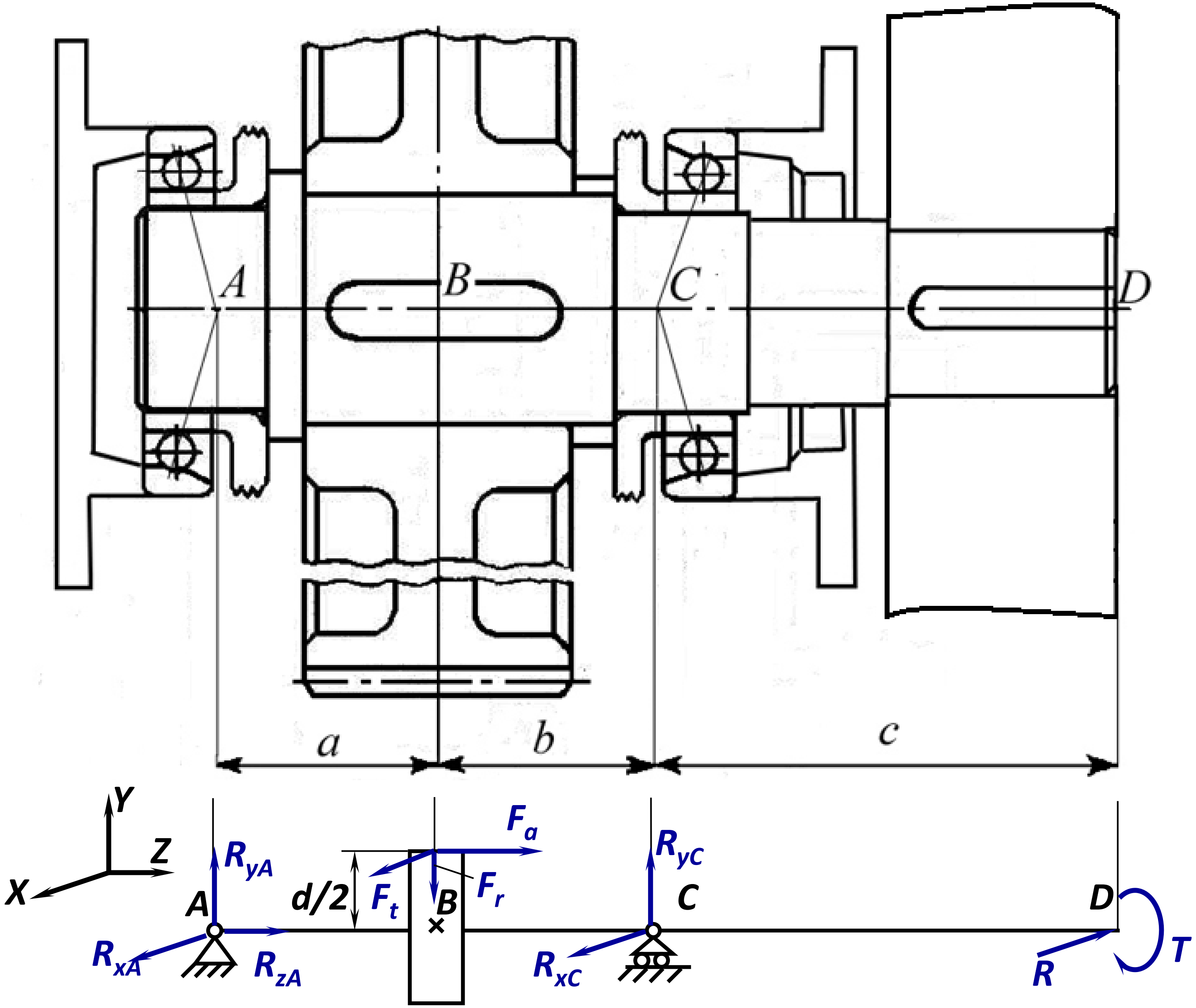




Output shaft



STATIC STRENGTH



R - load on the shaft from a belt drive (Step 2 (15))

$$R = 2 \cdot F_0 \cdot z \cdot \sin(\frac{\alpha_1}{2});$$

F_t , F_r, F_a - gear forces (Step 3_3)

$$F_t = \frac{2 \cdot T_1}{d_{W1}};$$

$$F_r = \frac{F_t \cdot tg\alpha_n}{\cos\beta};$$

$$F_a = F_t \cdot tg\beta.$$

T – second shaft torque (Step 1)

1. Draw the analytical model in the vertical plane and transfer all forces to the shaft;

2. Determine vertical support reactions $\boldsymbol{R_{yA}}$ and $\boldsymbol{R_{yC}}$

3. Plot the bending moment diagram in the vertical plane;

4. Draw the analytical model in the horizontal plane and transfer all forces to the shaft;

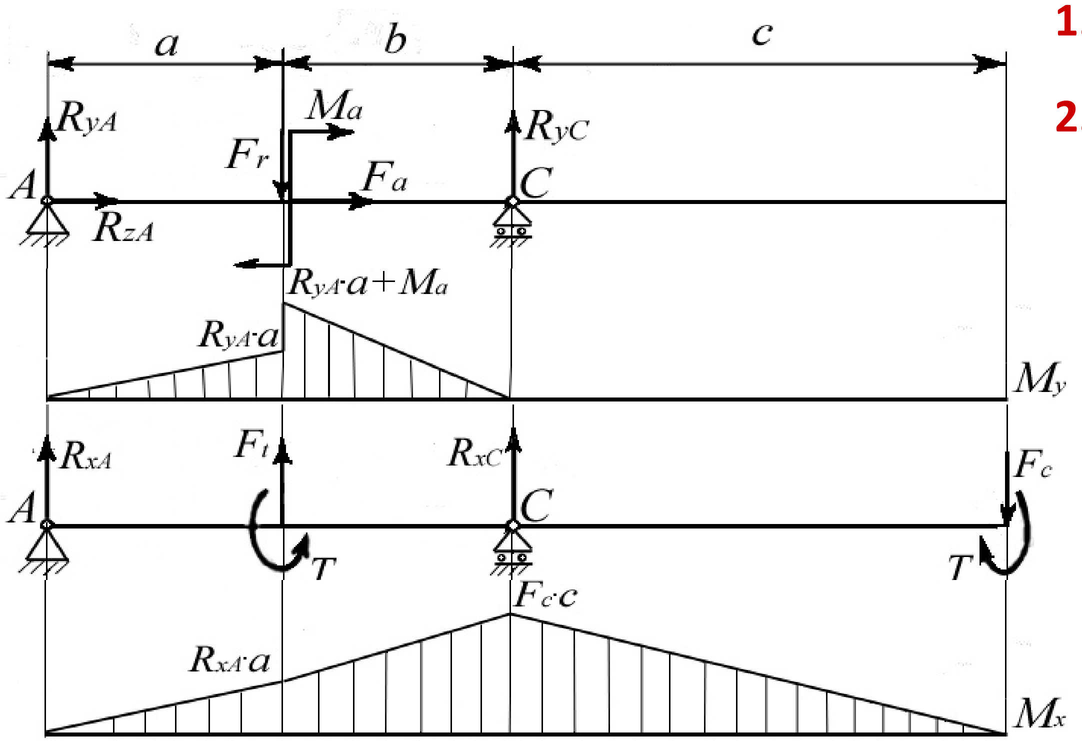
5. Determine horizontal support reactions $\boldsymbol{R_{xA}}$ and $\boldsymbol{R_{xC}}$

6. Plot the bending moment diagram in the horizontal plane;

7. Plot the total bending moment diagram $\left(M_{\Sigma} = \sqrt{M_x^2 + M_y^2}\right)$;

8. Plot the torsion moment diagram;

9. Plot the total moment diagram $\left(M_{tot} = \sqrt{M_t^2 + 0.75 \cdot T^2}\right)$.



1. $M_a = F_a \cdot \frac{d}{2}$.

2. $\sum M_A = 0: \; -F_r \cdot a - M_a + R_{yC} \cdot (a+b) = 0;$

$R_{yC} = \frac{F_r \cdot a + M_a}{a+b};$

$\sum M_c = 0: \; -R_{yA} \cdot (a+b) + F_r \cdot b - M_a = 0;$

$R_{yA} = \frac{F_r \cdot b - M_a}{a+b};$

Checking: $\sum F_{yi} = 0: \; R_{yA} - F_r + R_{yC} = 0.$

3. $0 \le x \le a; \quad M_y = R_{yA} \cdot x;$

$M_y(0) = 0; \quad M_y(a) = R_{yA} \cdot a;$

$a \le x \le a+b;$

$M_y = R_{yA} \cdot x + M_a - F_r \cdot (x-a);$

$M_y(a) = R_{yA} \cdot a + M_a; \; M_y(a+b) = 0.$

4. $T = F_t \cdot \frac{d}{2}$.

5. $\sum M_A = 0: \; F_t \cdot a + R_{xC} \cdot (a+b) - F_c \cdot (a+b+c) = 0;$

$R_{xC} = \frac{-F_t \cdot a + F_c \cdot (a+b+c)}{a+b};$

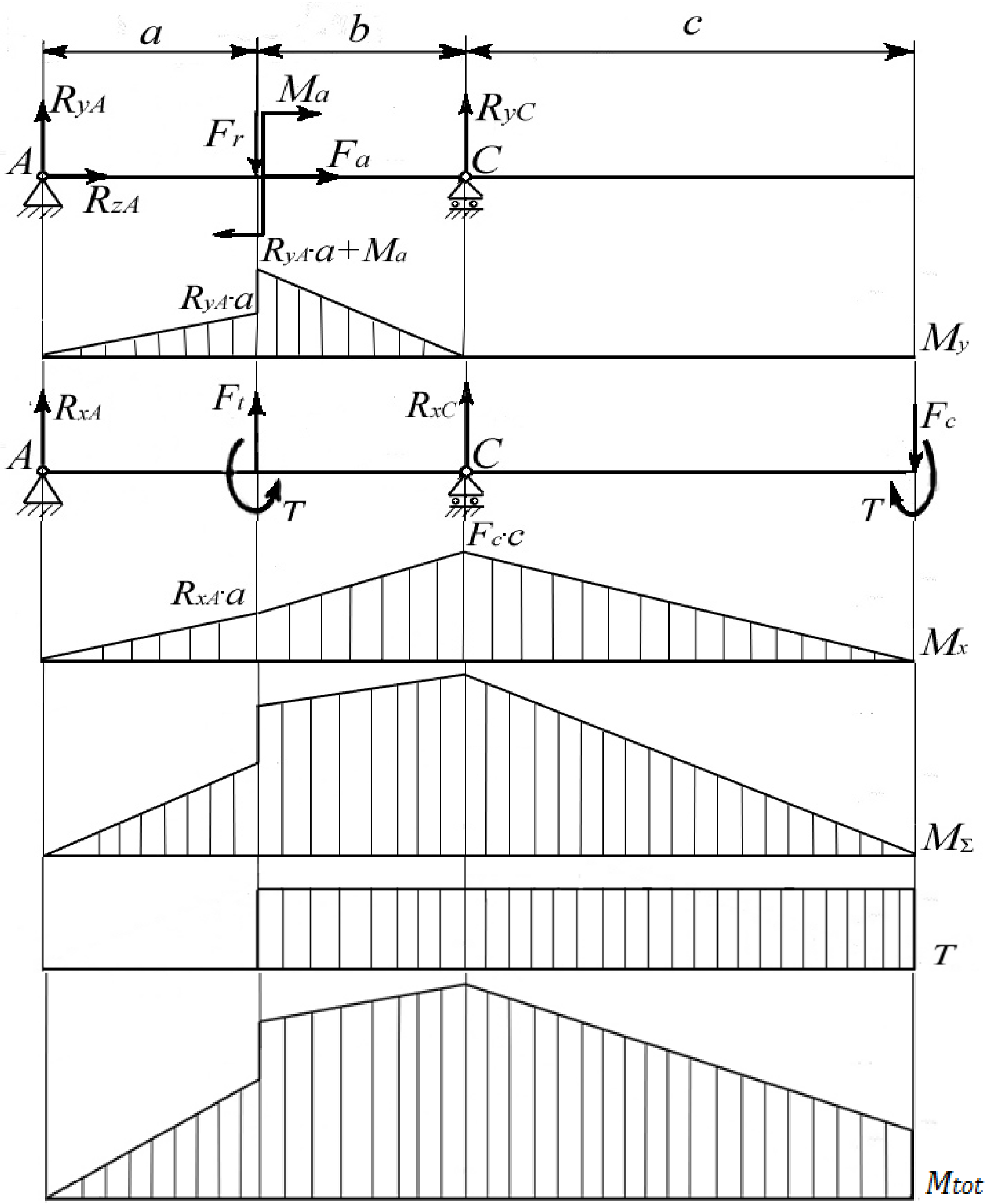
$\sum M_c = 0: \; -R_{xA} \cdot (a+b) - F_t \cdot b - F_c \cdot c = 0;$

$R_{xA} = \frac{-F_t \cdot b - F_c \cdot c}{a+b};$

Checking: $\sum F_{xi} = 0: \; R_{xA} + F_t + R_{xC} - F_c = 0.$

6. $0 \le x \le a; \; M_x = R_{xA} \cdot x; \; M_x(0) = 0; \; M_x(a) = R_{xA} \cdot a;$

$0 \le x \le c; \; M_x = F_c \cdot x; \; M_x(0) = 0; \; M_x(c) = F_c \cdot c.$



7. $M_\Sigma = \sqrt{M_x^2 + M_y^2};$

8. T

9. $M_{tot} = \sqrt{M_t^2 + 0.75 \cdot T^2};$

Calculation for static strength

$$\sigma = \frac{M}{W} \le [\sigma_{-1}];$$

$$M = M_{tot\ max}; \qquad W = \frac{\pi \cdot d^3}{32};$$

$$d = \sqrt[3]{\frac{M_{tot\,max}}{0.1 \cdot [\sigma_{-1}]}}.$$

$[\sigma_{-1}] = 40...120$ MPa.