Lab 3

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Unit System: Si unit

Pre-setting

Table – Variants of Task

	Fixed joint				Sliding joint/Small-sliding joints			
Variants	1	2	3	4	1	2	3	4
P, [N]	160000	185000	175000	155000	145000	150000	165000	170000

Variant №: 1

For fixed joint, $P = 160000$ N, and for sliding joint, $P = 145000$ N.

Table 1 – Material Properties

Materials	Ultimate tensile strength σ_{ult}, [MPa]	Proof strength σ_{02}, [MPa]	Shear strength* τ_{ult}, τ_{02} (% of tensile strength)	Modulus of elasticity E, [Gpa]	Shear modulus G, [Gpa]	Density, ρ, [g/cm^3]
30ХГСА	1100	850	63	210	78	7,85
ОТ4	700	600	50	110	80	4,5
ВТ20	1000	910	50	110	44	4,5
ВНС-2	1250	1100	60	190	76	7,8

Materials of eye and double eye are chosen to be **BT20** while the material of the bolt complex is chosen to be **30ХГСА**.

Fixed joint

Determine the bolt diameter

From shear stress

$$\tau_{cut} = \frac{P_{cut}}{A_{cut}} = \frac{2P}{\pi d^2} \Rightarrow d_{bolt} \geq \sqrt{\frac{2P}{\pi \tau_{ult}}} = 12.12 \text{ mm}$$

We round up to 16 mm.

$$\tau_{cut} = \frac{2P}{\pi d^2} = 398 \text{ MPa}$$

$$\eta = \frac{\tau_{ult}}{\tau_{cut}} = 1.7$$

From max cutting load of the bolt

Таблица 2

Номинальный диаметр гладкой части стержня болта, мм	Марка материала: 30ХГСА, 16ХСН, 40ХН2МА			30ХГСН2А	14Х17Н2		07Х16Н6	
	Температура, °С: 25	100 – 300	400	25	25	400	25	400
	Расчетная разрушающая нагрузка на срез, Н (кгс)							
4	8340 (850)	7950 (810)	–	–	6370(650)	4800(490)	–	–
5	13400 (1370)	13400 (1370)	–	–	10000(1020)	7450(760)	13330(1360)	12160(1240)
6	19300 (1970)	19300 (1970)	16500 (1680)	28000 (2850)	14410(1470)	10780(1100)	19310(1970)	17550(1790)
7	26400 (2690)	26400 (2690)	22400 (2280)	–	19700(2010)	14700(1500)	26270(2680)	23820(2430)
8	34300 (3500)	34300 (3500)	29200 (2980)	49700 (5070)	25680(2620)	19310(1970)	34410(3510)	31180(3180)
9	43700 (4450)	43700 (4450)	37100 (3780)	–	32650(3330)	24410(2490)	43530(4440)	39510(4030)
10	53900 (5490)	53900 (5490)	45800 (4650)	77500 (7900)	40290(4110)	30200(3080)	53820(5490)	48820(4980)
12	77500 (7900)	77500 (7900)	–	111800 (11400)	–	–	–	–
14	105000 (10700)	105000 (10700)	–	152100 (15500)	–	–	–	–
15	120700 (12300)	120700 (12300)	–	–	–	–	–	–
16	137300 (14000)	137300 (14000)	–	198200 (20200)	–	–	–	–
17	155000 (15800)	155000 (15800)	–	–	–	–	–	–
18	174600 (17800)	174600 (17800)	–	251100(25600)	–	–	–	–
20	214800 (21900)	214800 (21900)	–	311000 (31700)	–	–	–	–
22	260000 (26500)	260000 (26500)	–	375700 (38300)	–	–	–	–
24	310000 (31600)	310000 (31600)	–	447300 (45600)	–	–	–	–

ОСТ 1

According to the table, $[P_{cut}] = 120700 \text{ N}$

$P_{cut} = 80000 \text{ N} \leq [P_{cut}] = 120700 \text{ N}$ is true.

$$\eta = \frac{[P_{cut}]}{P_{cut}} = 1.5$$

Crumpling stress of the eye

For the eye, $a_{eye} = \dfrac{P}{d \cdot \sigma_{ult}} = \dfrac{160000}{0.016 \cdot 10^9} = 10 \text{ mm}.$

For the double eye, $a_{double\_eye} = \dfrac{P/2}{d \cdot \sigma_{ult}} = \dfrac{80000}{0.016 \cdot 10^9} = 5 \text{ mm}.$

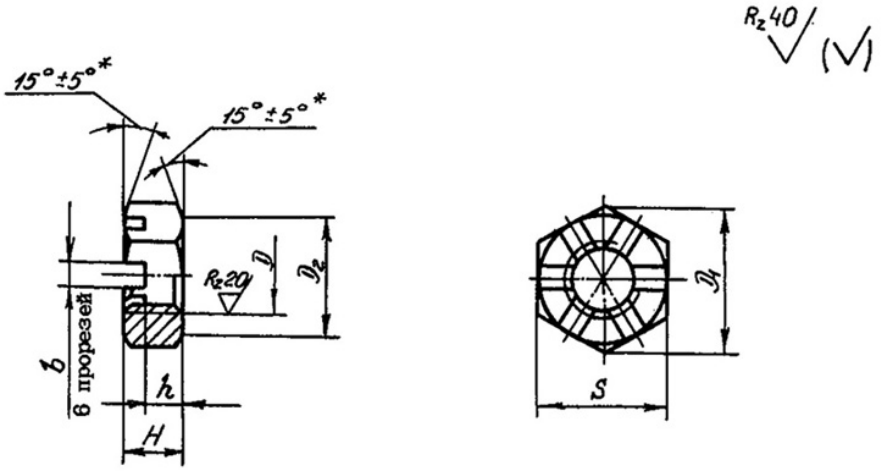
Thus, $[\sigma_{crump}] = K\sigma_{ult} = 1000 \text{ MPa}$

$\sigma_{eye} = \dfrac{P}{d \cdot a_{eye}} = \dfrac{160000}{0.016 \cdot 0.01} = 1000 \text{ MPa}$

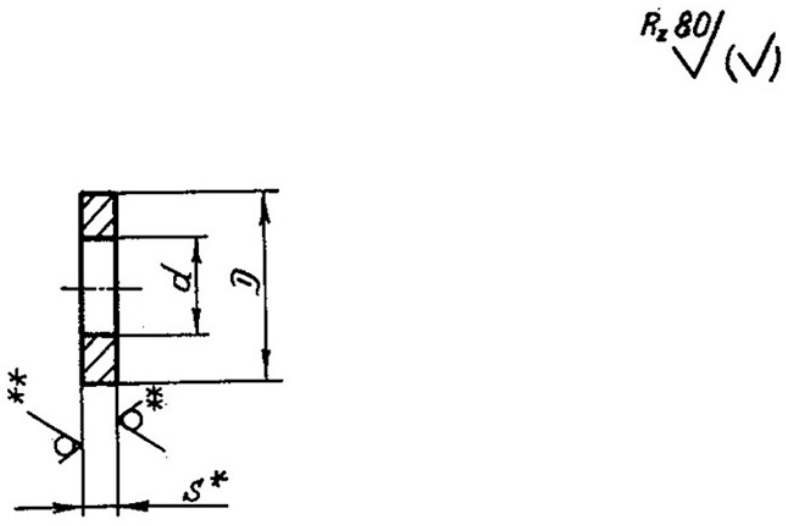
$\sigma_{double\_eye} = \dfrac{P/2}{d \cdot a_{double\_eye}} = \dfrac{80000}{0.016 \cdot 0.005} = 1000 \text{ MPa}$

$\eta_{eye} = \eta_{double\_eye} = 1$

Determine the length of the bolt



We will use a low self-locking hex nut. According to *ОСТ 1 33048-80 Гайки шестигранные прорезные низкие сталь*, we select a nut from steel 30ХГСА. Thread - M16x1.5. Nut height $H = 9$ mm. Turnkey size $S = 22$ mm. Head diameter $D_1 = 24.6$ mm and $D_2 = 21$ mm.



Take the washer from steel 30ХГСА according to *ОСТ 1 34507-80 Шайбы сталь*, we have $d_1 = 17$ mm and $d_2 = 32$ mm, and its height is 2 mm.

Taking into account the protruding threaded part of the bolt from the nut and its chamfer (according to the design rules, the threaded part of the bolt should protrude from the nut by 1-2 turns), then add the following value in addition to the bolt size:

$\Delta l = 1.5 \times 2 + 1.5 = 4.5$ mm.

$L = a_{eye} + 2a_{double\_eye} + \delta_{washer} + \delta_{nut} = 10 + 10 + 9 + 2 + 4.5 = 35.5$ mm.

We round up to $L = 36$ mm.

There is a standard bolt length according to *ОСТ 1 31132-80 Болты с шестигранной уменьшенной головкой и короткой резьбовой частью сталь* 36 mm.

Strength Design on break load

For the eye structure,

$x = \frac{P_{\text{break}}}{2 \cdot a \cdot \sigma_{\text{ut}}} = \frac{160000}{2 \cdot 0.01 \cdot 10^9} = 8$ mm.

$\sigma_{\text{break,eye}} = \frac{P_{\text{break}}}{A_{\text{break}}} = \frac{P_{\text{break}}}{(b-d) \cdot a} = \frac{P_{\text{break}}}{2 \cdot a \cdot x} = \frac{160000}{2 \cdot 0.01 \cdot 0.008} = 1000 \text{ MPa}$

$[\sigma_{\text{break,eye}}] = K_{\text{break}} \sigma_{\text{ult}} = \left(0.565 + 0.48 \cdot \frac{y}{x} - 0,1 \cdot \frac{b}{a}\right) \sigma_{\text{ult}} = (0.565 + 0.48 \cdot 1.4 - 0.1 \cdot 2) \cdot 1000 = 1037 \text{ MPa}$

$\sigma_{\text{break,eye}} \leq [\sigma_{\text{break,eye}}]$ is true.

$\eta_{\text{eye}} = \frac{[\sigma_{\text{break,eye}}]}{\sigma_{\text{break,eye}}} = 1.037$

For the double-eye structure,

$\sigma_{\text{break,double}-\text{eye}} = \frac{P_{\text{break}}}{A_{\text{break}}} = \frac{P_{\text{break}}}{(b-d) \cdot a} = \frac{P_{\text{break}}}{2 \cdot a \cdot x} = \frac{80000}{2 \cdot 0.005 \cdot 0.008} = 1000 \text{ MPa}$

$[\sigma_{\text{break,double}-\text{eye}}] = K_{\text{break}} \sigma_{\text{ult}} = \left(0.565 + 0.48 \cdot \frac{y}{x} - 0,1 \cdot \frac{b}{a}\right) \sigma_{\text{ult}} = (0.565 + 0.48 \cdot 1.4 - 0.1 \cdot 2) \cdot 1000 = 1037 \text{ MPa}$

$\sigma_{\text{break,double}-\text{eye}} \leq [\sigma_{\text{break,double}-\text{eye}}]$ is true.

$\eta_{\text{double-eye}} = \frac{[\sigma_{\text{break,double}-\text{eye}}]}{\sigma_{\text{break,double}-\text{eye}}} = 1.037$

Strength Design on cutting

From the drawing, $y^* = 16.3$ mm.

For the eye structure,

$\tau_{\text{cut,eye}} = \frac{P_{\text{cut}}}{F_{\text{cut}}} = \frac{P_{\text{cp}}}{2 \cdot a \cdot y^*} = \frac{160000}{2 \cdot 0.01 \cdot 0.0163} = 490.8$ MPa.

$[\tau_{\text{cut,eye}}] = 500$ MPa.

$\tau_{\text{cut,eye}} \leq [\tau_{\text{cut,eye}}]$ is true.

$\eta_{\text{eye}} = \frac{[\tau_{\text{cut,eye}}]}{\tau_{\text{cut,eye}}} = 1.02.$

For the double-eye structure,

$\tau_{\text{cut,double}-\text{eye}} = \frac{P_{\text{cut}}}{F_{\text{cut}}} = \frac{P_{\text{cp}}}{2 \cdot a \cdot y^*} = \frac{80000}{2 \cdot 0.005 \cdot 0.0163} = 490.8$ MPa.

$[\tau_{\text{cut,double-eye}}] = 500$ MPa.

$\tau_{\text{cut,double}-\text{eye}} \leq [\tau_{\text{cut,double-eye}}]$ is true.

$\eta_{\text{double-eye}} = \frac{[\tau_{\text{cut,double-eye}}]}{\tau_{\text{cut,double}-\text{eye}}} = 1.02.$

Sliding joint/Small-sliding joints

Determine the bolt diameter

From shear stress

$$\tau_{cut} = \frac{P_{cut}}{A_{cut}} = \frac{2P}{\pi d^2} \Rightarrow d_{bolt} \geq \sqrt{\frac{2P}{\pi \tau_{ult}}} = 11.54 \text{ mm}$$

We round up to 14 mm.

$$\tau_{cut} = \frac{2P}{\pi d^2} = 471 \text{ MPa}$$

$$\eta = \frac{\tau_{ult}}{\tau_{cut}} = 1.47$$

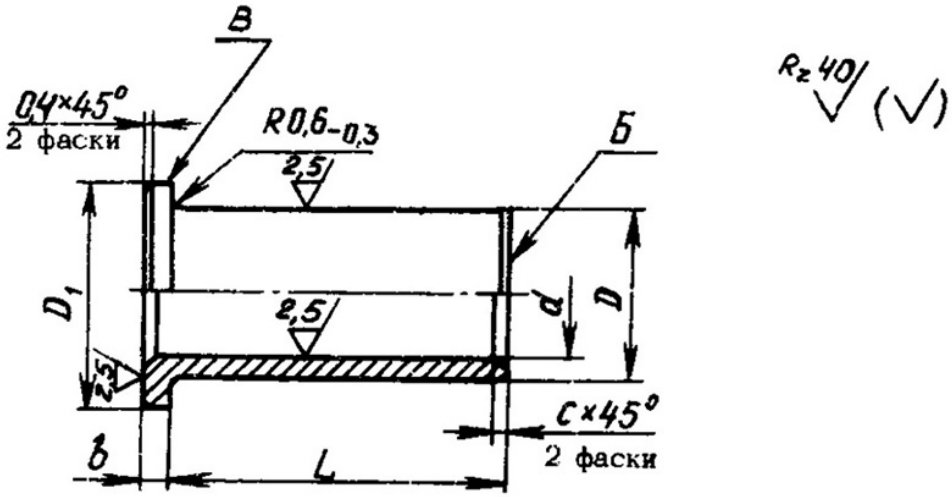
From max cutting load of the bolt

According to the table, $[P_{cut}] = 10500$ N

$P_{cut} = 72500 \text{ N} \leq [P_{cut}] = 105000 \text{ N}$ is true.

$$\eta = \frac{[P_{cut}]}{P_{cut}} = 1.45$$

Eye thickness



Crumpling along the inner diameter *d* of the bush

$[\sigma_{\text{CM}}] = K_{\text{CM}} \cdot \sigma_{\text{B}} = 0.2 \cdot 1000 = 200$ MPa.

$$\sigma_{\text{CM}} = \frac{P_{\text{CM}}}{F_{\text{CM}}} = \frac{P_{\text{CM}}}{2 \cdot d \cdot (L_{\text{BT}} + b)} \Rightarrow (L_{\text{BT}} + b) = \frac{P_{\text{CM}}}{2 \cdot d \cdot [\sigma_{\text{CM}}]} = \frac{145000}{2 \cdot 14 \cdot 200} = 25.9 \text{ mm}.$$

According to *ОСТ 1 11127-73 Втулки с буртиком для запрессовки бронза*, $b = 1.5$ mm. We choose $L_{\text{BT}} = 30$ mm.

$a_1 = 2 \cdot 30 + 2 = 62$ mm

$$\sigma_{\text{CM}} = \frac{P_{\text{CM}}}{F_{\text{CM}}} = \frac{P_{\text{CM}}}{2 \cdot d \cdot (L_{\text{BT}} + b)} = \frac{145000}{2 \cdot 14 \cdot (30 + 1.5)} = 164.4 \text{ MPa}.$$

$$\eta = \frac{[\sigma_{\text{CM}}]}{\sigma_{\text{CM}}} = \frac{200}{164.4} = 1.22.$$

Crumpling along the outer diameter *D* of the bush

According to *ОСТ 1 11127-73 Втулки с буртиком для запрессовки бронза*, $D = 17$ mm and $D_1 = 21$ mm.

$[\sigma_{\text{CM}}] = K \cdot \sigma_{\text{B}} = 1 \cdot 1000 = 1000$ MPa.

$$L_{\text{BT}} = \frac{P_{\text{CM}}}{2 \cdot D \cdot \sigma_B} = \frac{145000}{2 \cdot 17 \cdot 1000} = 4.26 \to 6 \text{ mm.}$$

$$a_2 = 2 \cdot 6 + 2 = 14 \text{ mm.}$$

$$\sigma_{\text{CM}} = \frac{P_{\text{CM}}}{2 \cdot D \cdot L_{\text{BT}}} = \frac{145000}{2 \cdot 17 \cdot 6} = 710.78 \text{ MPa.}$$

$$\eta = \frac{[\sigma_{\text{CM}}]}{\sigma_{\text{CM}}} = \frac{1000}{710.78} = 1.41.$$

Of the two options, choose the largest eye thickness. Then $a = 62$ mm.

Bolted connection parameters

We will use a low self-locking hex nut. According to *ОСТ 1 33048-80 Гайки шестигранные прорезные низкие сталь*, we select a nut from steel 30ХГСА. Thread - M14x1.5. Nut height $H = 8$ mm. Turnkey size $S = 19$ mm. Head diameter $D_1 = 21.1$ mm and $D_2 = 18$ mm.

Take the washer from steel 30ХГСА according to *ОСТ 1 34507-80 Шайбы сталь*, we have $d_1 = 15$ mm and $d_2 = 28$ mm, and its height is 2 mm.

$\Delta l = 1.5 \times 2 + 1.5 = 4.5$ mm.

$L = 62 + 10 + 2 \cdot 1.5 + 8 + 2 + 4.5 = 89.5$ mm.

We round up to 90 mm.

Check on tensile strength

$$K_{\text{break}} = 0.565 + 0.48 \cdot 1 - 0.1 \cdot 2 = 0.845$$

$$[\sigma_{\text{break}}] = K_{\text{break}} \cdot \sigma_{\text{B}} = 0.845 \cdot 1000 = 845 \text{ MPa.}$$

$$x = \frac{P}{2 \cdot a \cdot K_{\text{break}} \cdot \sigma_{\text{B}}} = \frac{145000}{2 \cdot 62 \cdot 0.845 \cdot 1000} = 1.38 \Rightarrow x = 2 \text{ mm.}$$

$$b = 2x + D = 2 \cdot 2 + 17 = 21 \text{ mm.}$$

$$\sigma_{\text{break}} = \frac{P}{F_{\text{break}}} = \frac{P}{(b - D) \cdot a} = \frac{145000}{(21 - 17) \cdot 62} = 584.68 \text{ MPa.}$$

$$\eta = \frac{[\sigma_{\text{break}}]}{\sigma_{\text{break}}} = \frac{845}{584.68} = 1.45.$$

Check on shear strength

From the drawing, $y^* = 9.7$ mm.

$$\tau_{\text{cp}} = \frac{P_{\text{cp}}}{2 \cdot a \cdot y^*} = \frac{145000}{2 \cdot 62 \cdot 9.7} = 120.55 \text{ MPa.}$$

$$[\tau_{\text{cp}}] = \tau_{\text{B}} = 500 \text{ MPa.}$$

$$\eta = \frac{[\tau_{\text{cp}}]}{\tau_{\text{cp}}} = \frac{500}{120.55} = 4.15.$$

Design Parameters

Fixed joint

Eye

Material: BT20

Thickness: $a = 10$ mm

Diameter: $d = 16$ mm

$x = 8$ mm

$y^* = 16.3$ mm

$b = 32$ mm

Double Eye

Material: BT20

Thickness: $a = 5$ mm

Diameter: $d = 16$ mm

$x = 8$ mm

$y^* = 16.3$ mm

$b = 32$ mm

Bolt

Material: 30ХГСА

Diameter: $d = 16$ mm

Height: $H = 9$ mm

Turnkey size: $S = 22$ mm

Head diameter: $D_1 = 24.6$ mm and $D_2 = 21$ mm

Length: $L = 36$ mm

Washer

Material: 30ХГСА

$d_1 = 17$ mm

$d_2 = 32$ mm

Height: $h = 2$ mm

Sliding joint

Eye

Material: BT20

Diameter: $d = 17$ mm

$a = 62$ mm

$x = 2$ mm

$b = 21$ mm

$y^* = 9.7$ mm

Double eye

Material: BT20

Diameter: $d = 14$ mm

$x = 2$ mm

$b = 21$ mm

$y^* = 9.7$ mm

Bolt

Material: 30ХГСА

Diameter: $d = 14$ mm

Height: $H = 8$ mm

Turnkey size $S = 19$ mm

Head diameter $D_1 = 21.1$ mm and $D_2 = 18$ mm

$L = 90$ mm

Sleeve

Material: Bronze

$b = 1.5$ mm

$L = 30$ mm

$D = 17$ mm

$D_1 = 21$ mm

$d = 14$ mm

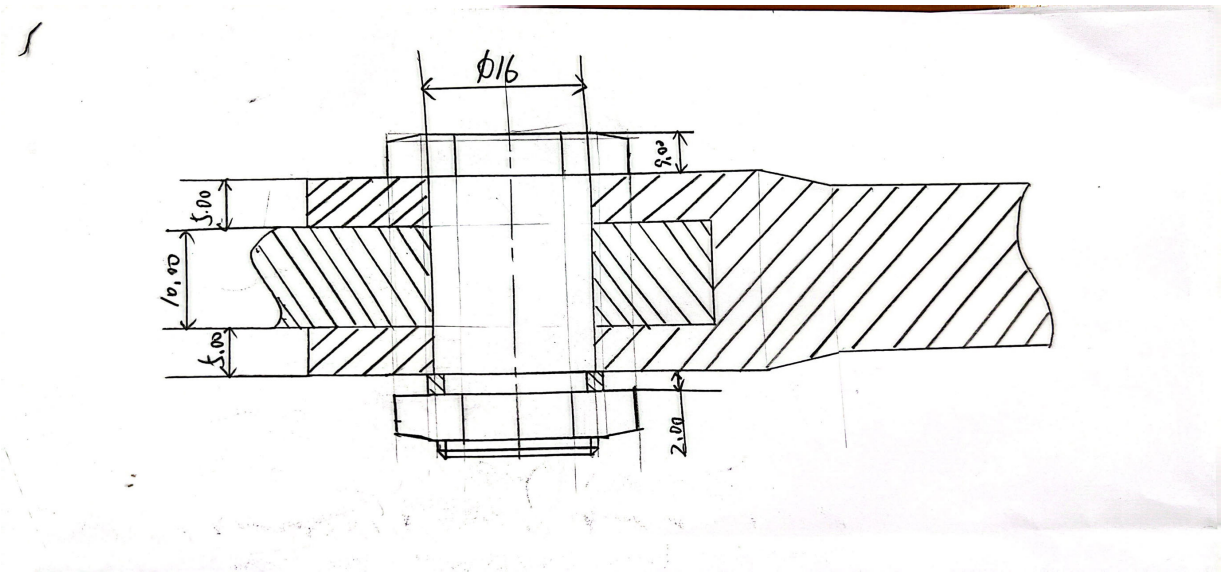
Washer

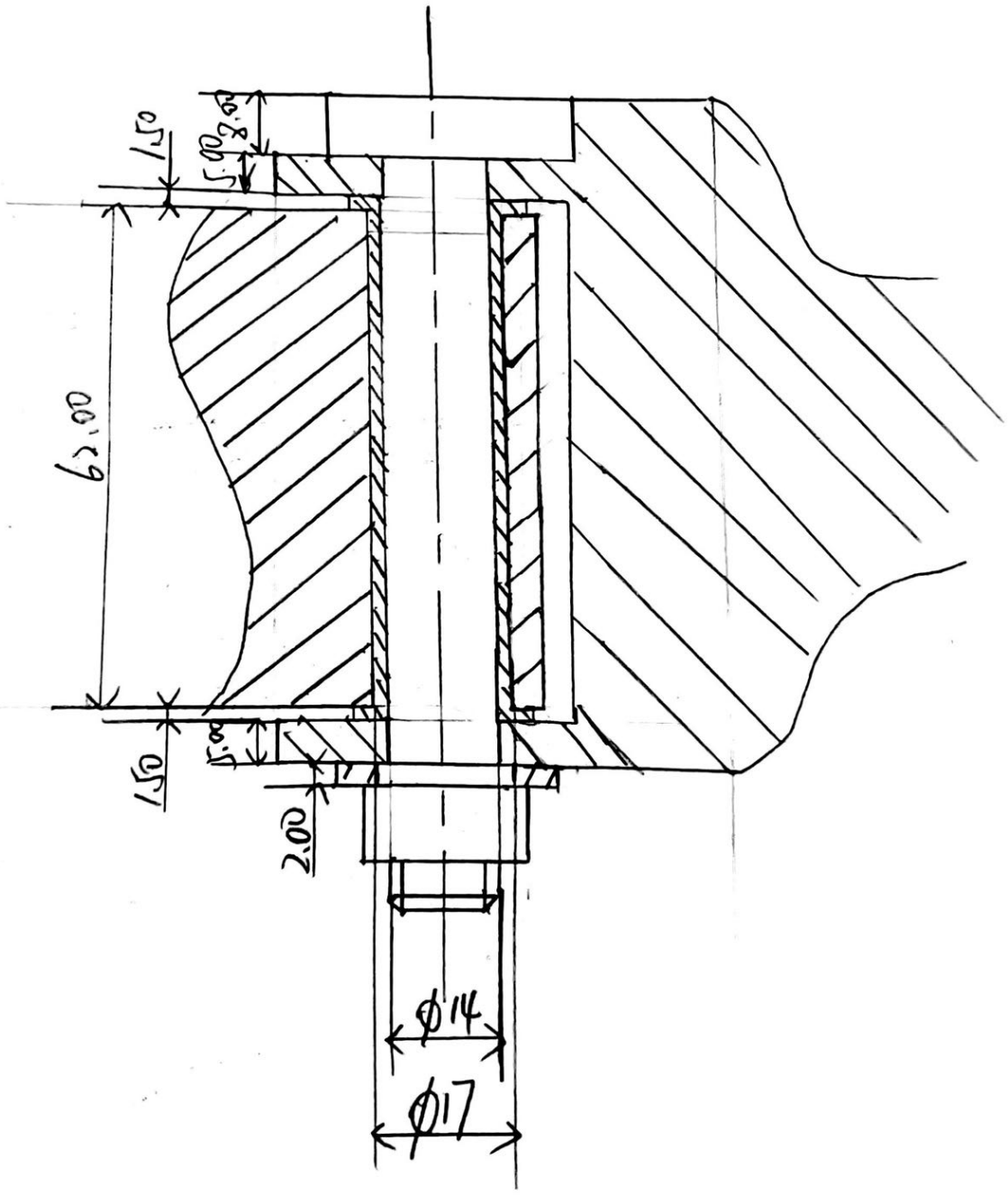
Material: 30ХГСА

$d_1 = 15$ mm and $d_2 = 28$ mm

Height: $h = 2$ mm

Sketch




1.50
2.80
6.00
1.50
2.00
φ14
φ17