Friction brakes and clutches

i **Calculation without errors.**
ii **Project information**

? **Input section**

1.0 Units, calculation of energies, loading moments, selection of materials and coefficients

1.1	Calculation units	SI Units (N, mm, kW...)	
1.2	Method of calculating energy and load	A. Brake calculation	

1.3 Brake calculation

1.4	Initial kinetic energy of the mechanism	Ek [J]	735000.00	
1.5	Load / unload moment (+ / -)	ML [Nm]	122.980	
1.6	Reduced moment of inertia	Ired	56.5221479	[kg*m²]
1.7	Initial speed of the brake disc (drum)	n1	1540	[/min]
1.8	Brake disc (drum) end speed	n2	0	[/min]
1.9	Required braking time	t	7.14	[s]
1.10	Theoretical braking torque	Mcalc	1399.624	[Nm]
1.11	Service coefficient	KA	1.10 / 1.00	[~] ☐
1.12	Torque for brake design	Mk	**1539.586**	[Nm]
1.13	Brake heating energy	Eh	**805802.828**	[J]

1.14 Calculation of the clutch (starting)

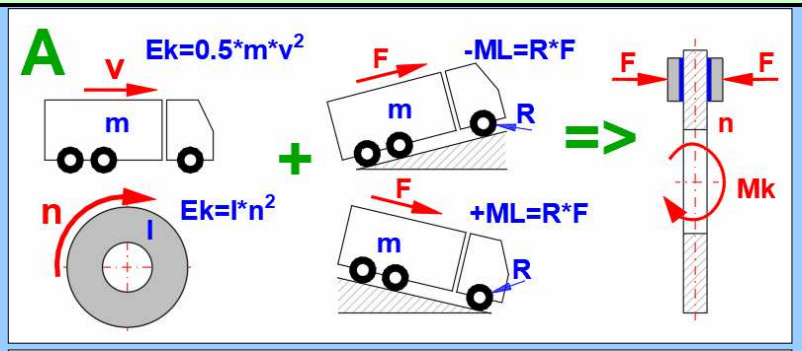
1.15	Final kinetic energy of the mechanism	Ek [J]	39200.00	
1.16	Load / unload moment (+ / -)	ML [Nm]	42.724	
1.17	Reduced moment of inertia	Ired	1.143875635	[kg*m²]
1.18	Drive power (electric motor, internal combusti	Pw	60.000	[kW]
1.19	Clutch speed (drive side)	n1	2500	[/min]
1.20	Clutch speed (mechanism side)	n2	0	[/min]
1.21	Drive torque	Me	229.183	[Nm]
1.22	Service coefficient	KA	1.30 / 1.37	[~] ☐
1.23	Torque for clutch design	Mk	**297.938**	[Nm]
1.24	Clutch efficiency	η	0.950	[~]
1.25	Torque available to achieve Ek	Mu	66.138	[Nm]
1.26	Clutch engagement time (mechanism start-up)	t	2.26 / 2.26	[s] ☑
1.27	Actual end kinetic energy achieved	Ek'	39200.000	[J]
1.28	Energy for the temperature rise of the clutch	Eh	**67918.175**	[J]

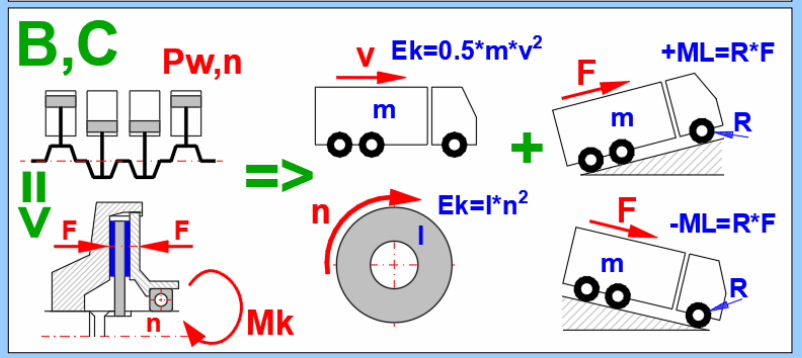
1.29 Clutch check (constant load)

1.30	Drive power (electric motor, internal combusti	Pw	90.000	[kW]
1.31	Speed	n	2000	[/min]
1.32	Drive torque	Me	429.718	[Nm]
1.33	Service coefficient	KA	1.37 / 1.37	[~] ☑
1.34	Torque for clutch design	Mk	**588.714**	[Nm]

1.35 Preliminary design of shaft diameters (steel)

1.36	Material of the shaft	A. Common structural steel (Rm = 500)		
1.37	- Main power-transmitting shafts	DA	90.70	[mm]
1.38	- Small, short shafts	DB	74.70	[mm]





1.39 Design of the KA coefficient

1.40	Driving machine	E. Internal combustion engine - 4 cylin
1.41	Driven / Braked mechanism, load	A. Occasional full load
1.42	Daily usage	4 h

1.43 Selection of friction material

1.44 30. FERODO DS2000 - Dry (FERODO) .....(f=0.48, pmax: 2.5, disk brakes) ☑

1.45	Coefficient of dynamic friction	f	0.48	0.48	[~]
1.46	Coefficient of static friction	f0	---	---	[~]
1.47	Max. sliding speed	vmax	45	45	[m/s]
1.48	Max. friction surface pressure	pmax	2.5	2.5	[MPa]
1.49	Permissible temperature (operating)	Tmax	480	480	[°C]

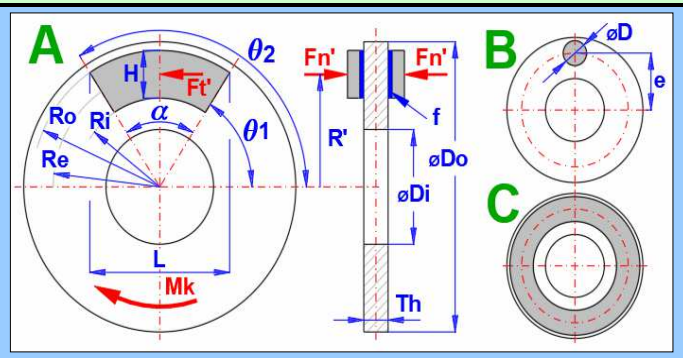
1.50 Selection of brake/clutch material (disc, drum, housing....)

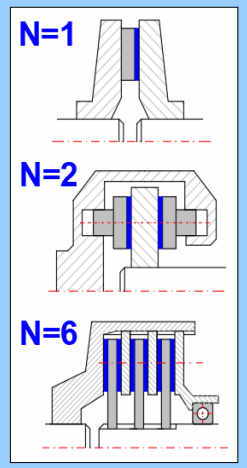
1.51 A. Steel (7850) ☑

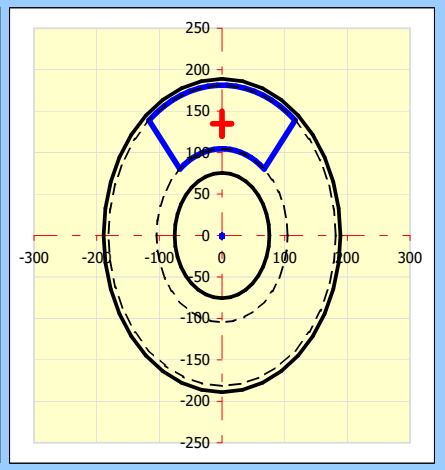
1.52	Density	Ro	7850.00	7850	[kg/m³]
1.53	Specific heat capacity	c	450.000	450	[J/kg/K]
1.54	Thermal conductivity	lambda	50	50	[W/m/K]

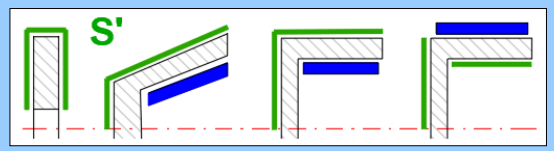
2.0 Disc brakes / clutches

2.1	**Basic input values**				
2.2	Braking / transfer torque	Mk [Nm]	1539.586	1539.586	☑
2.3	Friction coefficient	f [~]	0.48	0.48	☑
2.4	**Friction segment definition**				
2.5	Shape of the friction segment		A. Annular sector pad		
2.6	Calculation method		A. Uniform wear		
2.7	Number of friction surfaces	N	2	[~]	
2.8	Outer radius of the friction segment	Ro	181.382	[mm]	
2.9	Height of friction segment	H [mm]	76.720	~76.72	☑
2.10	Inner radius of the friction segment	Ri	104.662	[mm]	
2.11	Segment angle	α	80.00	[°]	
2.12	Equivalent radius	Re	143.022	[mm]	
2.13	Radius of action of the normal force Fn'	R'	134.841	[mm]	
2.14	Complementary angles	θ1,θ2	50 / 130	[°]	
2.15	Segment width	L	233.180	[mm]	
2.16	Fill factor	cF [~]	1.00	~ 1	☑
2.17	Contact area of one friction segment	S	15320.65795	[mm²]	
2.18	Sliding area for the friction segment	S''	68942.96078	[mm²]	
2.19	**Values for one friction surface**				
2.20	Braking / transmission torque	Mk'	769.793	[Nm]	
2.21	Friction force	Ft'	5382.356	[N]	
2.22	Normal force	Fn'	11213.243	[N]	
2.23	Friction speed	vmax [m/s]	29.251	< 45	
2.24	Maximum pressure	pmax [MPa]	1.000	< 2.5	
2.25	Heat flux density through the surface S''	q	1.637	[W/mm²]	
2.26	Approximate temperature rise	ΔT1	127.36	[°C]	
2.27	Friction surface warming	ΔT2	173.47	[°C]	
2.28	**Finding a solution (GoalSeek)**				
2.29	03. Setting the desired value "pmax" by changing value "Ro + H"				
2.30	Required parameter value	pmax [MPa]	1		
2.31	**Brake disc calculation**				
2.32	Outer diameter	Do [mm]	378	[mm]	☑
2.33	Inner diameter	Di [mm]	151.2	[mm]	
2.34	Brake disc thickness	Th [mm]	19	[mm]	
2.35	Number of disks	N'	1	[~]	
2.36	Surface	S'	211093.9148	[mm²]	
2.37	Volume	V	1791044.466	[mm³]	
2.38	Weight	m	14.05969906	[kg]	



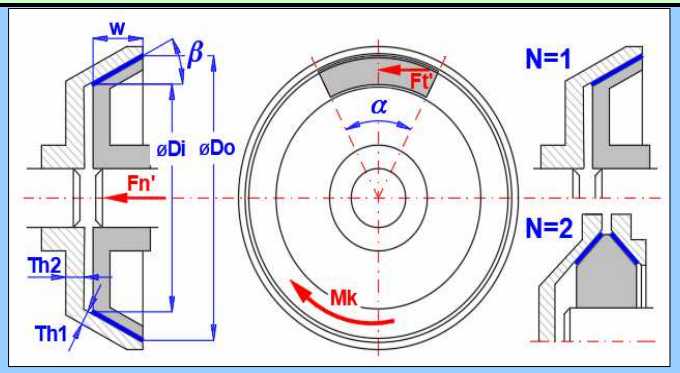


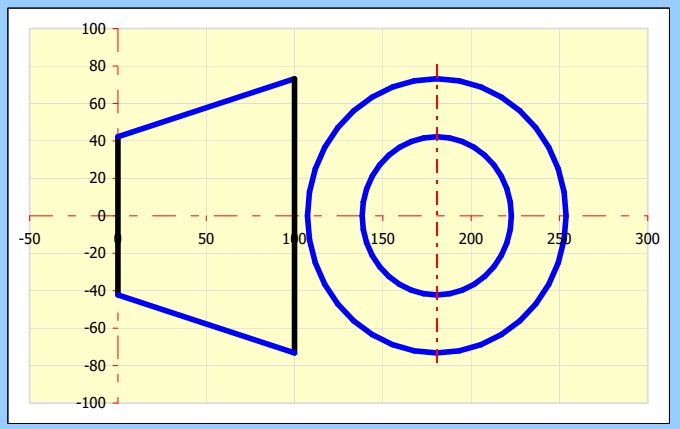


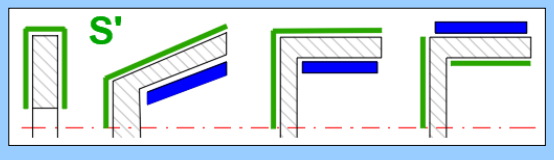


3.0 Cone brakes / clutches

3.1	**Basic input values**				
3.2	Braking / transfer torque	Mk [Nm]	1539.586	1539.586	☑
3.3	Friction coefficient	f [~]	0.48	0.48	☑
3.4	**Friction segment definition**				
3.5	Shape of the friction segment		B. Complete conical surface		
3.6	Calculation method		A. Uniform wear		
3.7	Number of friction surfaces	N	1	[~]	
3.8	Outer diameter of the conical surface	Do	146.425	[mm]	
3.9	Inner diameter of the conical surface	Di [mm]	84.490	~84.49	☑
3.10	Segment angle	α	70.00	[°]	
3.11	Cone angle	β	17.21	[°] ☑	
3.12	Cone width	w	100.000	[mm] ☐	
3.13	Equivalent diameter	De	115.458	[mm]	
3.14	Contact area of one friction segment	S	37971.49583	[mm²]	
3.15	Sliding area for the friction segment	S''	37971.49583	[mm²]	
3.16	**Values for one friction surface**				
3.17	Braking / transmission torque	Mk'	1539.586	[Nm]	
3.18	Friction force	Ft'	26669.286	[N]	
3.19	Normal force	Fn'	16435.858	[N]	
3.20	Friction speed	vmax [m/s]	11.807	< 45	
3.21	Maximum pressure	pmax [MPa]	2.000	< 2.5	
3.22	Heat flux density through the surface S''	q	2.972	[W/m²]	
3.23	Approximate temperature rise	ΔT1	708.71	[°C]	
3.24	Friction surface warming	ΔT2	629.90	[°C]	
3.25	**Finding a solution (GoalSeek)**				
3.26	03. Setting the desired value "pmax" by changing value "Do + Di"				
3.27	Required parameter value	pmax [MPa]	2		
3.28	**Friction cone calculation**				
3.29	Wall thickness	Th1	7	[mm] ☑	
3.30	Wall thickness	Th2	10	[mm]	
3.31	Surface	S'	46866.89055	[mm²]	
3.32	Volume	V	321866.5908	[mm³]	
3.33	Weight	m	2.526652737	[kg]	

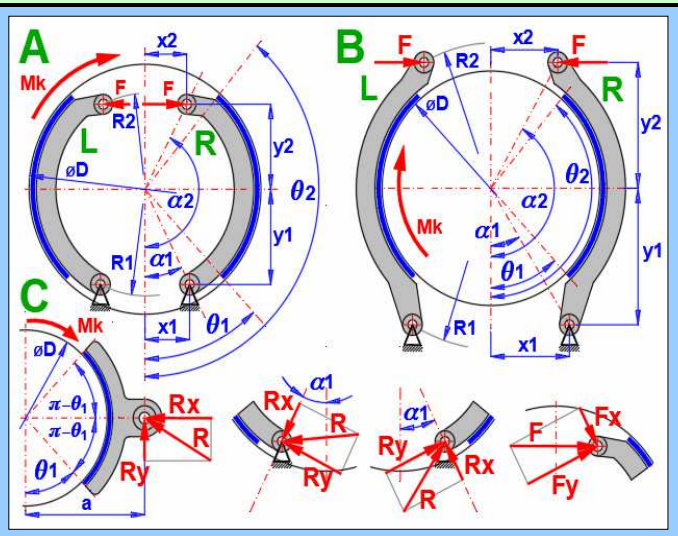


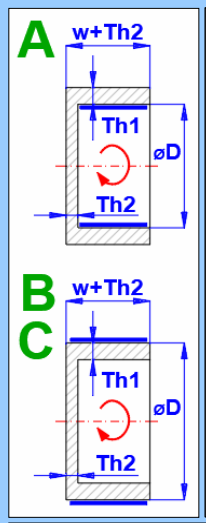


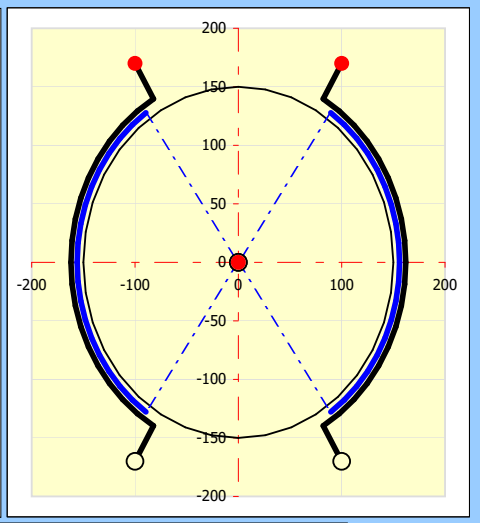


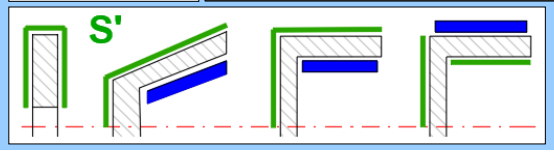
4.0 Drum brakes / clutches

4.1	**Basic input values**				
4.2	Braking / transfer torque	Mk [Nm]	500.000	1539.586	☐
4.3	Friction coefficient	f [~]	0.4	0.48	☐
4.4	**Friction segment definition**				
4.5	Brake / clutch type		B. Outer shoes		
4.6	Number of trailing (L) / leading (R) shoes	NL/NR	1	1	
4.7	Drum diameter	D	300.000		[mm]
4.8	Shoe face width	w	100.000		[mm]
4.9	Pin position (radius and angle)	R1/α1	197.23	30.47	[mm]/[°] ☑
4.10	Pin position (x, y coordinates)	x1/y1	100.00	-170.00	[mm] ☐
4.11	Position of force (radius and angle)	R2/α2	197.23	149.53	[mm]/[°] ☑
4.12	Position of force (x, y coordinates)	x2/y2	100.00	170.00	[mm] ☐
4.13	Braking segment angle from / to	θ1,θ2	35.00	145.00	[°]
4.14	Distance of the caliper pin from the drum axis	a	171.877		[mm]
4.15	Fill factor	cF [~]	1.00	~ 0.95	☐
4.16	Contact area of one friction segment	S	28797.93266		[mm²]
4.17	Sliding area for the friction segment	S''	94247.77961		[mm²]
4.18	**Values for friction surfaces**				
4.19	Braking torque L	ML	194.177		[Nm]
4.20	Braking torque R	MR	305.823		[Nm]
4.21	Contact force FL = FR = F	F	1932.404		[N]
4.22	Force components F	Fx/Fy	979.7677	1665.605	[N]
4.23	Reaction in shoe pin L	RL	1252.101		[N]
4.24	Reaction components in pin L	RLx/RLy	1050.656	681.0864	[N]
4.25	Reaction in shoe pin R	RR	3437.336		[N]
4.26	Reaction components in pin R	RRx/RRy	-1213.022	3216.187	[N]
4.27	Friction speed	vmax [m/s]	0.000	< 45	
4.28	Maximum pressure in the trailing shoe (L)	pmaxL [MPa]	0.153	< 2.5	
4.29	Maximum pressure in the leading shoe (R)	pmaxR [MPa]	0.241	< 2.5	
4.30	Heat flux density through the surface S''	q	0.000		[W/m²]
4.31	Approximate temperature rise	ΔT1	0.00		[°C]
4.32	Friction surface warming	ΔT2	0.00		[°C]
4.33	**Finding a solution (GoalSeek)**				
4.34	10. Setting the desired value "pmaxR" by changing value "D"				
4.35	Required parameter value	pmaxR [MPa]	2		
4.36	**Brake drum calculation**				
4.37	Wall thickness	Th1	10		[mm] ☑
4.38	Wall thickness	Th2	12		[mm]
4.39	Surface	S'	345449.5282		[mm²]
4.40	Volume	V	2607521.902		[mm³]
4.41	Weight	m	20.46904693		[kg]



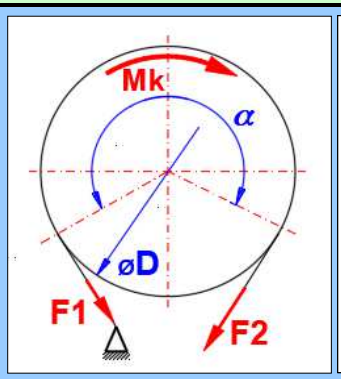


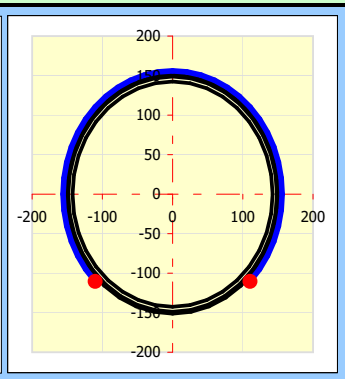


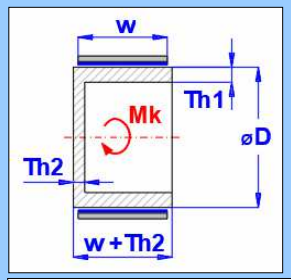


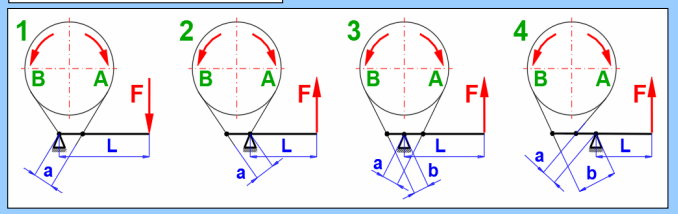
5.0 Band brakes / clutches

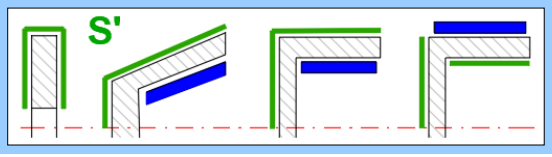
5.1	**Basic input values**				
5.2	Braking / transfer torque	Mk [Nm]	510.815	1539.586	☐
5.3	Friction coefficient	f [~]	0.3	0.48	☐
5.4	**Friction segment definition**				
5.5	Number of brake bands	N	1	[~]	
5.6	Outer diameter of the drum	D	300.000	[mm]	
5.7	Band angle	α	270.00	[°]	
5.8	Band width	w	100.000	[mm]	
5.9	Contact area of one friction segment	S	70685.83471	[mm²]	
5.10	Sliding area for the friction segment	S''	94247.77961		
5.11	**Values for one band**				
5.12	Friction force	Ft'	3405.431	[N]	
5.13	Tensile force	F1'	4500.000	[N]	
5.14	Tensile force	F2'	1094.569	[N]	
5.15	Friction speed	vmax [m/s]	0.000	< 45	
5.16	Maximum pressure	pmax [MPa]	0.300	< 2.5	
5.17	Heat flux density through the surface S''	q	0.000	[W/m²]	
5.18	Approximate temperature rise	ΔT1	0.00	[°C]	
5.19	Friction surface warming	ΔT2	0.00	[°C]	
5.20	**Finding a solution (GoalSeek)**				
5.21	01. Setting the desired value "pmax" by changing value "Mk"				
5.22	Required parameter value	pmax [MPa]	0.3		
5.23	**Calculation of the force F for different types of structure**				
5.24	Construction type		3. Differential band brake		
5.25	Sense of rotation		A. Clockwise		
5.26	Dimension	L	400.000	[mm]	
5.27	Dimension	a	60.000	[mm]	
5.28	Dimension	b	30.000	[mm]	
5.29	Control force	F	173.315	[N]	
5.30	**Brake drum calculation**				
5.31	Wall thickness	Th1	12	[mm]	☑
5.32	Wall thickness	Th2	15	[mm]	
5.33	Surface	S'	349470.7668	[mm²]	
5.34	Volume	V	2146021.942	[mm³]	
5.35	Weight	m	16.84627224	[kg]	









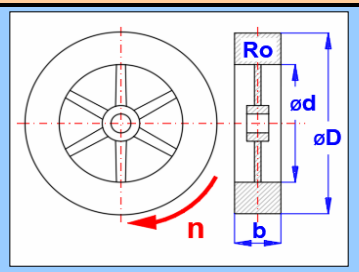


? **Additions section**

6.0 Calculation of kinetic energy of rotating and moving mass

6.1 Kinetic energy of rotating masses 1

☐	Quantity	D	d	b	Ro	n	ω	rg	m	I	Ek(r)
ID	[-]	[mm]	[mm]	[mm]	[kg/m³]	[/min]	[rad/s]	[mm]	[kg]	[kg*m²]	[J]
1	4	620	450	200	400	1540	161.2684	270.8551	45.71646	3.353874	43612.94
2	0	0	0	0	0	0	0	---	0	0	0
3	0	0	0	0	0	0	0	---	0	0	0
4	0	0	0	0	0	0	0	---	0	0	0
5	0	0	0	0	0	0	0	---	0	0	0
								Σ	45.71646	3.353874	43612.94



6.2 Kinetic energy of rotating masses 2

☐	Quantity	m	rg	n	I	Ek(r)
ID	[-]	[kg]	[mm]	[/min]	[kg*m²]	[J]
1	1	1000	500	100	250	13707.78
2	0	0	0	0	0	0
3	0	0	0	0	0	0
4	0	0	0	0	0	0
5	0	0	0	0	0	0
					Σ	13707.78

Designations in tables

Ro ..... Density
n ..... Speed
ω ..... Angular speed
rg ..... Radius of inertia
m ..... Weight
I ..... Moment of inertia
Ek ..... Kinetic energy
v ..... Speed

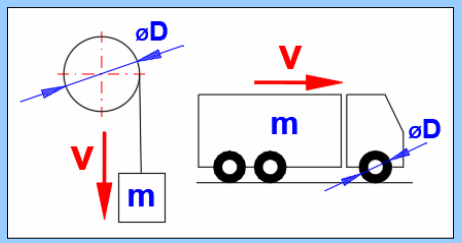
6.3 Kinetic energy of rotating masses 3

☐	Quantity	I	n	Ek(r)
ID	[-]	[kg*m²]	[/min]	[J]
1	1	2.2	1500	27141.41
2	0	0	0	0
3	0	0	0	0
4	0	0	0	0
5	0	0	0	0
			Σ	27141.41

6.4 Kinetic energy of linearly moving masses

☑	Quantity	m	v	v	Ek(m)
ID	[-]	[kg]	[m/s]	[km/h]	[J]
1	1	1600	7	25.2	39200
2	0	0	0	0	0
3	0	0	0	0	0
4	0	0	0	0	0
5	0	0	0	0	0
					39200

D	n
[mm]	[/min]
620	215.6293
0	0
0	0
0	0
0	0



6.5 Kinetic energy - sum and move to [1]

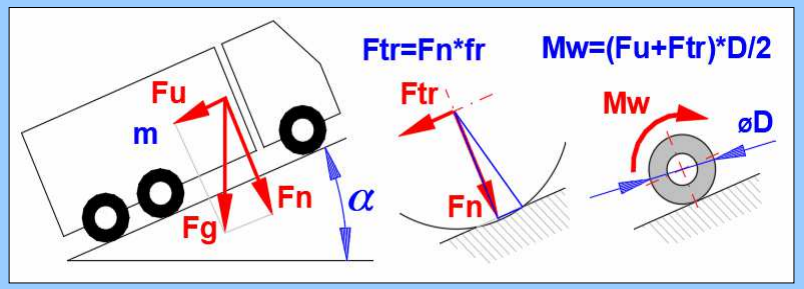
6.6 The sum of the marked values Ek **39200.00** [J]

6.7 Move value to [1.4] or [1.15]

7.0 Calculation of brake / clutch load torque

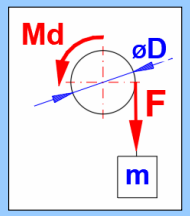
7.1 Vehicle movement

7.2	Vehicle weight	m	1600.00	[kg]
7.3	Rising / falling	α	5.00	[°]
7.4	Rising / falling	av	8.75	[%]
7.5	Vehicle wheel diameter	D	620.000	[mm]
7.6	Rolling Resistance	fr	0.0150	[~]
7.7	Wheel speed	nw	215	[/min]
7.8	Brake / clutch speed	ne	2500	[/min]
7.9	Force from dead weight	Fg	15696.00	[N]
7.10	Force to overcome the climb	Fu	1368.00	[N]
7.11	Normal force	Fn	15636.27	[N]
7.12	Rolling resistance force	Ftr	234.54	[N]
7.13	Moment on the wheel	Mw	496.79	[Nm]
7.14	Gear ratio	i	11.628	[~]
7.15	Loading / unloading torque	ML	**42.72**	[Nm]
7.16	Move value to [1.5] or [1.16]			



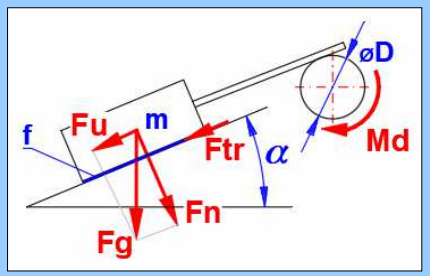
7.17 Elevator, crane

7.18	Weight	m	1000.00	[kg]
7.19	Diameter of the drum	D	500.000	[mm]
7.20	Drum speed	nd	30	[/min]
7.21	Brake / clutch speed	ne	30	[/min]
7.22	Force	F	9810.00	[N]
7.23	Moment on the drum	Md	2452.50	[Nm]
7.24	Gear ratio	i	1.000	[~]
7.25	Loading / unloading torque	ML	**2452.50**	[Nm]
7.26	Move value to [1.5] or [1.16]			



7.27 Movement on inclined plane

7.28	Weight	m	1000.00	[kg]
7.29	Angle of inclined plane	α	0.00	[°]
7.30	Friction coefficient	f	0.1000	[~]
7.31	Diameter of the drum	D	2000.000	[mm]
7.32	Drum speed	nd	500	[/min]
7.33	Brake / clutch speed	ne	3000	[/min]
7.34	Force	Fg	9810.0	[N]
7.35	Force to overcome the climb	Fu	0.00	[N]
7.36	Normal force	Fn	9810.00	[N]
7.37	Friction force	Ftr	981.00	[N]
7.38	Moment on the drum	Md	981.00	[Nm]
7.39	Gear ratio	i	6.000	[~]
7.40	Loading / unloading torque	ML	**163.50**	[Nm]
7.41	Move value to [1.5] or [1.16]			



8.0 Calculation of brake / clutch warming

8.1 Dimensions and material parameters of the disc, drum, case...

8.2 1. Disc brakes / clutches ☑

8.3	Surface	S	211093.9148	[mm²]
8.4	Weight	m	14.060	[kg]
8.5	Specific heat capacity	c	450.0000	[J/kg/K]

8.6 Single braking / clutch engagement

8.7	Energy absorbed by the brake (clutch)	Eh	805802.83	[J] ☑
8.8	Temperature rise per cycle	ΔT	127.36	[°C]

8.9 Repeated braking / clutch engagement (iterative calculation)

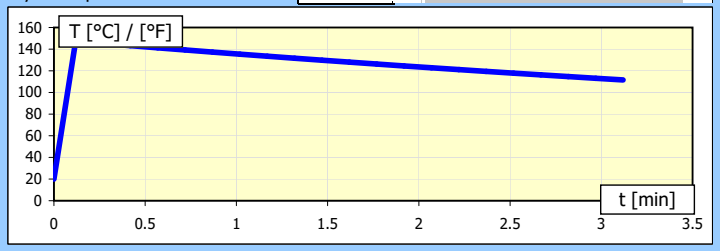
8.10	Air temperature	TA	20.00	[°C]
8.11	Air velocity	vA	25.00	[m/s]
8.12	Braking / clutch engagement time	dt	7.14	[s] ☑
8.13	Time interval	t1	180.00	[s]
8.14	Ventilation factor	fv	7.00	[~]
8.15	Minimum temperature	Tmin	235.92	[°C]
8.16	Maximum temperature	Tmax	363.28	[°C]

8.17 Repeated braking/clutch engagement (cumulative calculation)

8.18	Estimation of temperature rise	ΔTg [°C]	343.30	343.3	☑
8.19	Coefficient of heat transfer by radiation	αR	25.40		[W*m^-2/K]
8.20	Coefficient of heat transfer by convection	αC	7.40		[W*m^-2/K]
8.21	Total heat transfer coefficient	α	77.20		[W*m^-2/K]
8.22	Maximum temperature	Tmax	363.28		[°C]

8.23 Graph A - Heating and cooling for one cycle

8.24 Cycle sequence number: 1



8.25 Graph B - Heating and cooling for repeated braking / clutch engagement