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RACK ANALYSIS (CYLINDRICAL GEAR)

Drawing or article number:
Gear 1: 0.000.0
Gear 2: 0.000.0

Calculation method Plastic according to VDI 2545:1981-modified (YF Method B)
Steel wheels: calculated roughly according to DIN 3990!

		---- Pinion ---------- Rack -
Power (W)	[P]	12.801
Speed (1/min)	[n]	191.0
Torque (Nm)	[T]	0.640
Application factor	[KA]	1.25
Required service life (h)	[H]	1000.00
Gear driving (+) / driven (-)		+ -

Working flank gear 1: Right flank
Sense of rotation gear 1 clockwise
Gearbox type: Gear with partly closed housing

1. TOOTH GEOMETRY AND MATERIAL

(geometry calculation according to ISO 21771:2007, DIN ISO 21771)

		---- Pinion ---------- Rack -	
Running center distance (mm)	[a]	29.000	
Center distance tolerance		No backlash	
Rack height (mm)	[Hz]	15.000	
Normal module (mm)	[mn]	1.0000	
Pressure angle at normal section (°)	[alfn]	20.0000	
Helix angle at reference circle (°)	[beta]	0.0000	
Number of teeth	[z]	30	63.6620
Rack length (mm)	[l]		200.000
Facewidth (mm)	[b]	15.00	15.00
Hand of gear		Spur gear	
Accuracy grade	[Q-DIN3961:1978]	6	6
Inner diameter (mm)	[di]	8.00	
Inner diameter of gear rim (mm)	[dbi]	0.00	

Material
Gear 1: POM (VDI2736), Thermoplastic (POM, PPA, etc.), untreated
VDI2736/VDI2545 [S B F Wd C]
Woehler line tooth root stress from file Z014-POM_VDI2736.DAT
S-N curve (Woehler line) Hertzian pressure from file Z014-POM_VDI2736.DAT
Gear 2: C45 (1), Through hardened steel, unalloyed, through hardened
ISO 6336-5 Figure 5/6 (MQ)

		------- GEAR 1 --------	GEAR 2 --
Surface hardness		HBW 0	HBW 186
Tooth root temperature (°C)	[TR]	70.0	70.0

Flank temperature (°C)	[TF]	70.0	70.0
Tooth root strength at NL (N/mm²)	[σFadm]	29.10	210.00
Strength against Hertzian pressure at NL (N/mm²)	[σHadm]	28.80	638.99
Tensile strength (N/mm²)	[σB]	45.20	700.00
Yield point (N/mm²)	[σS]	41.00	490.00
Young's modulus (N/mm²)	[E]	2217	206000
Poisson's ratio	[v]	0.440	0.300
Roughness average value DS, flank (µm)	[RAH]	0.00	1.05
Roughness average value DS, root (µm)	[RAF]	0.00	3.00
Mean roughness height, Rz, flank (µm)	[RZH]	0.00	8.00
Mean roughness height, Rz, root (µm)	[RZF]	0.00	20.00

Gear reference profile 1 :

Reference profile	1.25 / 0.38 / 1.0 ISO 53:1998 Profil A	
Dedendum coefficient	[hfP*]	1.250
Root radius factor	[rhofP*]	0.380 (rhofPmax*=0.472)
Addendum coefficient	[haP*]	1.000
Tip radius factor	[rhoaP*]	0.000
Protuberance height coefficient	[hprP*]	0.000
Protuberance angle	[alfprP]	0.000
Tip form height coefficient	[hFaP*]	0.000
Ramp angle	[alfKP]	0.000

not topping

Gear reference profile 2 :

Reference profile	1.25 / 0.38 / 1.0 ISO 53:1998 Profil A	
Dedendum coefficient	[hfP*]	1.250
Root radius factor	[rhofP*]	0.380 (rhofPmax*=0.472)
Addendum coefficient	[haP*]	1.000
Tip radius factor	[rhoaP*]	0.000
Protuberance height coefficient	[hprP*]	0.000
Protuberance angle	[alfprP]	0.000
Tip form height coefficient	[hFaP*]	0.000
Ramp angle	[alfKP]	0.000

not topping

Summary of reference profile gears:

Dedendum reference profile	[hfP*]	1.250	1.250
Tooth root radius Refer. profile	[rofP*]	0.380	0.380
Addendum Reference profile	[haP*]	1.000	1.000
Protuberance height coefficient	[hprP*]	0.000	0.000
Protuberance angle (°)	[alfprP]	0.000	0.000
Tip form height coefficient	[hFaP*]	0.000	0.000
Ramp angle (°)	[alfKP]	0.000	0.000

Type of profile modification: none (only running-in)

Tip relief (µm)	[Ca]	20.4	10.7

Lubrication type Dry-running

Ambient temperature (°C)	[TU]	20.000

		---- Pinion ---------- Rack -
Transverse module (mm)	[mt]	1.000
Pressure angle at pitch circle (°)	[alft]	20.000
Working transverse pressure angle (°)	[alfwt]	20.000
Working pressure angle at normal section (°)	[alfwn]	20.000
Helix angle at operating pitch circle (°)	[betaw]	0.000

Base helix angle (°)	[betab]	0.000	
Sum of profile shift coefficients	[Summexi]	0.0000	
Profile shift coefficient	[x]	0.0000	0.0000
Tooth thickness (Arc) (module) (module)	[sn*]	1.5708	1.5708
Tip alteration (mm)	[k*mn]	0.000	0.000
Reference diameter (mm)	[d]	30.000	14.000
Base diameter (mm)	[db]	28.191	
Tip diameter (mm)	[da,Hz]	32.000	15.000
(mm)	[da,Hz.e/i]	32.000 / 31.975	15.000 / 14.998
Tip diameter allowances (mm)	[Ada,AHz.e/i]	0.000 / -0.025	-0.000 / -0.002
Tip form diameter (mm)	[dFa]	32.000	15.000
(mm)	[dFa.e/i]	32.000 / 31.975	15.000 / 14.998
Active tip diameter (mm)	[dNa.e/i]	32.000 / 31.975	15.000 / 14.998
Operating pitch diameter (mm)	[dw]	30.000	14.000
Root diameter (mm)	[df]	27.500	12.750
Generating Profile shift coefficient	[xE.e/i]	-0.0742 / -0.1154	-0.0742 / -0.1154
Generated root diameter with xE (mm)	[df.e/i]	27.352 / 27.269	12.676 / 12.635
Theoretical tip clearance (mm)	[c]	0.250	0.250
Effective tip clearance (mm)	[c.e/i]	0.378/ 0.324	0.367/ 0.324
Active root diameter (mm)	[dNf]	28.532	13.163
(mm)	[dNf.e/i]	28.534 / 28.532	13.173 / 13.163
Root form diameter (mm)	[dFf]	28.534	13.087
(mm)	[dFf.e/i]	28.470 / 28.438	13.013 / 12.971
Reserve (dNf-dFf)/2 (mm)	[cF.e/i]	0.048 / 0.031	0.201 / 0.151
Addendum (mm)	[ha = mn * (haP*+x)]	1.000	1.000
(mm)	[ha.e/i]	1.000 / 0.988	1.000 / 0.998
Dedendum (mm)	[hf = mn * (hfP*-x)]	1.250	1.250
(mm)	[hf.e/i]	1.324 / 1.365	1.324 / 1.365
Roll angle at dFa (°)	[xsi_dFa.e/i]	30.775 / 30.668	
Roll angle to dNa (°)	[xsi_dNa.e/i]	30.775 / 30.668	
Roll angle to dNf (°)	[xsi_dNf.e/i]	8.963 / 8.939	
Roll angle at dFf (°)	[xsi_dFf.e/i]	8.088 / 7.598	
Tooth height (mm)	[h]	2.250	2.250
Virtual gear no. of teeth	[zn]	30.000	
Normal tooth thickness at tip circle (mm)	[san]	0.737	0.843
(mm)	[san.e/i]	0.693 / 0.648	0.790 / 0.759
Normal space width at root circle (mm)	[efn]	0.000	0.661
(mm)	[efn.e/i]	0.000 / 0.000	0.607 / 0.577
Max. sliding velocity at tip (m/s)	[vga]	0.048	0.058
Specific sliding at the tip	[zetaa]	0.319	0.569
Specific sliding at the root	[zetaf]	-1.320	-0.469
Sliding factor on tip	[Kga]	0.161	0.193
Sliding factor on root	[Kgf]	-0.193	-0.161
Pitch on reference circle (mm)	[pt]	3.142	
Base pitch (mm)	[pbt]	2.952	
Transverse pitch on contact-path (mm)	[pet]	2.952	
Length of path of contact (mm)	[ga, e/i]	5.372 (5.372/ 5.340)	
Length T1-A (mm)	[T1A]	2.199 (2.199/ 2.205)	
Length T1-B (mm)	[T1B]	4.619 (4.619/ 4.592)	
Length T1-C (mm)	[T1C]	5.130 (5.130/ 5.130)	
Length T1-D (mm)	[T1D]	5.151 (5.151/ 5.157)	
Length T1-E (mm)	[T1E]	7.571 (7.571/ 7.545)	
Diameter of single contact point B (mm)	[d-B]	29.666 (29.666/ 29.649)	
Diameter of single contact point D (mm)	[d-D]	30.014 (30.014/ 30.018)	
Transverse contact ratio	[eps_a]	1.820	
Transverse contact ratio with allowances	[eps_a.e/m/i]	1.820 / 1.814 / 1.809	

Overlap ratio	[eps_b]	0.000
Total contact ratio	[eps_g]	1.820
Total contact ratio with allowances	[eps_g.e/m/i]	1.820 / 1.814 / 1.809

2. FACTORS OF GENERAL INFLUENCE

		---- Pinion ---------- Rack -
Nominal circum. force at pitch circle (N)	[Ft]	42.7
Axial force (N)	[Fa]	0.0
Radial force (N)	[Fr]	15.5
Normal force (N)	[Fnorm]	45.4
Nominal circumferential force per mm (N/mm)	[w]	2.84
Only as information: Forces at operating pitch circle:		
Nominal circumferential force (N)	[Ftw]	42.7
Axial force (N)	[Faw]	0.0
Radial force (N)	[Frw]	15.5
Circumferential speed reference circle (m/s)	[v]	0.30
Circumferential speed operating pitch circle (m/s)	[v(dw)]	0.30
Correction factor	[CM]	0.800
Gear blank factor	[CR]	1.000
Basic rack factor	[CBS]	0.975
Material coefficient	[E/Est]	0.021
Singular tooth stiffness (N/mm/µm)	[c']	0.317
Meshing stiffness (N/mm/µm)	[cg]	0.512
Dynamic factor	[KV]	1.000
User specified factor KHb:		
Face load factor - flank	[KHb]	1.000
- Tooth root	[KFb]	1.000
- Scuffing	[KBb]	1.000
Transverse load factor - flank	[KHa]	1.000
- Tooth root	[KFa]	1.000
- Scuffing	[KBa]	1.000

Number of load cycles (in mio.)	[NL]	11.460	5.400
Rack length (mm)	[l]		200.000

3. TOOTH ROOT STRENGTH

Calculation of Tooth form coefficients according method: B

		---- Pinion ----------	Rack -
Calculated with manufacturing profile shift	[xE.e]	-0.0742	-0.0742
Tooth form factor	[YF]	1.34	1.13
Stress correction factor	[YS]	1.93	2.48
Load application angle (°)	[alfFen]	17.19	20.00
Bending moment arm (mm)	[hF]	0.91	1.05
Tooth thickness at root (mm)	[sFn]	2.03	2.36
Tooth root radius (mm)	[roF]	0.57	0.38

(hF* = 0.908/ 1.046 sFn* = 2.033/ 2.357 roF* = 0.574/ 0.380)
(den/hen (mm) =
30.014/ 14.175 dsFn/hsFn(mm) = 27.767/ 12.866 alfsFn(°) = 30.00/ 30.00 qs = 1.772/ 3.102)

Contact ratio factor	[Yeps]	1.000	
Helix angle factor	[Ybet]	1.000	
Effective facewidth (mm)	[beff]	15.00	15.00
Nominal stress at tooth root (N/mm²)	[sigF0]	7.34	7.97
Tooth root stress (N/mm²)	[sigF]	9.18	9.96
Permissible bending stress at root from data tables			
Notch sensitivity factor	[YdrelT]	1.000	1.015
Surface factor	[YRrelT]	1.000	0.957
size factor (Tooth root)	[YX]	1.000	1.000
Notice: When using Wohler lines from data files, the factors YdrelT, YRrelT, YX will be interpolated according to the breakpoints NLstatic and NLendurance following ISO.			
Finite life factor	[YNT]	1.000	1.000
	[YdrelT*YRrelT*YX*YNT]	1.000	0.971
Alternating bending factor (mean stress influence coefficient)	[YM]	1.000	1.000
Stress correction factor	[Yst]	2.00	
Yst*sigFlim (N/mm²)	[sigFE]	58.20	420.00
Permissible tooth root stress (N/mm²)	[sigFP=sigFG/SFmin]	48.50	339.95
Limit strength tooth root (N/mm²)	[sigFG]	58.20	407.94
Required safety	[SFmin]	1.20	1.20
Safety for tooth root stress	[SF=sigFG/sigF]	6.34	40.96
Transmittable power (W)	[WRating]	67.66	436.90

4. SAFETY AGAINST PITTING (TOOTH FLANK)

		---- Pinion ---------- Rack -	
Zone factor	[ZH]	2.495	
Elasticity factor (√N/mm²)	[ZE]	29.404	
Contact ratio factor	[Zeps]	0.853	
Helix angle factor	[Zbet]	1.000	
Effective facewidth (mm)	[beff]	15.00	
Nominal contact stress (N/mm²)	[sigH0]	19.16	
Contact stress at operating pitch circle (N/mm²)	[sigHw]	21.42	
Lubrication coefficient at NL	[ZL]	1.000	1.024
Speed coefficient at NL	[ZV]	1.000	0.921
Roughness coefficient at NL	[ZR]	1.000	1.000
Material pairing coefficient at NL	[ZW]	1.000	1.000
Notice: When using Wohler lines from data files, the factors ZL, ZV, ZR, ZW will be interpolated according to the breakpoints NLstatic and NLendurance following ISO.			
Finite life factor	[ZNT]	1.000	1.183
	[ZL*ZV*ZR*ZNT]	1.000	1.115
Limited pitting is permitted:	No		
Size factor (flank)	[ZX]	1.000	1.000
Permissible contact stress (N/mm²)	[sigHP=sigHG/SHmin]	32.00	669.29
Pitting stress limit (N/mm²)	[sigHG]	28.80	602.36
Required safety	[SHmin]	0.90	0.90
Safety factor for contact stress at operating pitch circle			
	[SHw]	1.34	28.12
Transmittable power (W)	[WRating]	19.12	12498.15

4a. WEAR

Line load at reference diameter (N/mm)	[w]	2.84
Line load at reference diameter (N/mm)	[K_A*K_γ*K_V*$K_{H\beta}$*$K_{H\alpha}$*w]	3.56

Loss factor	[H_V]	0.088
Calculation only for Gear 1		
Length of active flank (mm)	[l_{Fl}]	1.86
Wear factor ($mm^3/Nm/10^6$)	[k_W]	3.40000
Data from file k_W: Z014-POM_VDI2736.DAT		
Normal tooth thickness in pitch circle (mm)	[s_n]	1.57
Maximum permissible wear (%)	[W_{limit}]	15.00
Permissible wear on flank (mm)	[δ_{Wlimn}]	0.24
Wear removal (mm)	[δ_{Wn}]	0.02060
Wear removal (mg)	[=lFL*b*z*ro*δWn]	24.5
Required safety	[S_{Wmin}]	1.10
Safety against wear	[S_W]	11.44

Calculation for safety against shearing for plastics		
Normal tooth thickness in the active root diameter (mm)	[s_{dNf}-δWn]	1.81
Shear stress (N/mm²)	[τ_{nom}]	1.57
Notch effect coefficient	[K_T]	1.25
Permitted shearing strength (N/mm²)	[τ_B]	16.21
Required safety	[S_{Tmin}]	2.50
Safety shearing	[S_T]	8.26

$\tau_B = 0.557 * \sigma_{Fadm}$; $S_T = \tau_B / (\tau_{nom} * K_T)$

Calculation of local wear with speeds and load distribution according to method A:
Calculation was not carried out. (Contact analysis under load is required.)

Important note:
the kw wear coefficients are usually determined using a plastic/steel pairing..
The coefficients may be very different if pairings of other materials are used..
This calculation is designed to give an indication of possible service life,
however it has not yet been checked exhaustively in real life..

5. BENDING

According to VDI2545:1981			
Tooth deformation (µm)	[fa]	13.292	
Permissible tooth deformation (µm)	[fazul]	100.000	
Required safety	[Sdel]	1.000	
Safety against deformation	[Sdelmin]	7.523	

Experimental method using tooth stiffness according	ISO6336:2006:		
Tooth deformation (µm)	[faExp]	13.329	0.143
Permissible tooth deformation (µm)	[fazulExp]	113.224	113.224
Required safety	[Sdel]	1.000	
Safety against jamming	[SdelExp]	8.495	789.350

6. MEASUREMENTS FOR TOOTH THICKNESS

		---- Pinion ----------	Rack -
Tooth thickness tolerance		DIN 3967 cd25	DIN 3967 cd25
Tooth thickness allowance (normal section) (mm)	[As.e/i]	-0.054 / -0.084	-0.054 / -0.084
Number of teeth spanned	[k]	4.000	
(Internal toothing: k = (Measurement gap number)			
Base tangent length (no backlash) (mm)	[Wk]	10.753	

Actual base tangent length (span) (mm)	[Wk.e/i]	10.702 / 10.674	
(mm)	[ΔWk.e/i]	-0.051 / -0.079	
Diameter of measuring circle (mm)	[dMWk.m]	30.149	
Theoretical diameter of ball/pin (mm)	[DM]	1.706	1.944
Effective diameter of ball/pin (mm)	[DMeff]	1.750	2.000
Radial single-ball measurement backlash free (mm)	[MrK]	16.244	15.766
Radial single-ball measurement (mm)	[MrK.e/i]	16.179 / 16.143	15.692 / 15.651
Diameter of measuring circle (mm)	[dMMr.m]	29.939	
Diametral measurement over two balls without clearance (mm)	[MdK]	32.488	
Diametral two ball measure (mm)	[MdK.e/i]	32.359 / 32.286	
Diametral measurement over pins without clearance (mm)	[MdR]	32.488	
Measurement over pins according to DIN 3960 (mm)	[MdR.e/i]	32.359 / 32.286	
Measurement over 3 pins (axial) according to AGMA 2002 (mm)			
	[dk3A.e/i]	32.359 / 32.286	
Chordal tooth thickness (no backlash) (mm)	[sc]	1.570	1.571
Actual chordal tooth thickness (mm)	[sc.e/i]	1.516 / 1.486	1.517 / 1.487
Reference chordal height from da.m (mm)	[ha]	1.014	0.999
Tooth thickness (Arc) (mm)	[sn]	1.571	1.571
(mm)	[sn.e/i]	1.517 / 1.487	1.517 / 1.487
Backlash free center distance (mm)	[aControl.e/i]	28.852 / 28.769	
Backlash free center distance, allowances (mm)	[jta]	0.148 / 0.231	
Tip clearance (mm)	[c0.i(aControl)]	0.094	0.094
Center distance allowances (mm)	[Aa.e/i]	-0.000 / -0.000	
Circumferential backlash from Aa (mm)	[jtw_Aa.e/i]	0.000 / 0.000	
Radial backlash (mm)	[jrw.e/i]	0.231 / 0.148	
Circumferential backlash (transverse section) (mm)	[jtw.e/i]	0.168 / 0.108	
Normal backlash (mm)	[jn.e/i]	0.158 / 0.101	
Torsional angle for fixed rack:			
Entire torsional angle (°)	[j.tSys]	0.0064/ 0.0041	

7. GEAR ACCURACY

		---- Pinion ----------	Rack -
According to DIN 3961:1978			
Accuracy grade	[Q-DIN3961]	6	6
Profile form deviation (µm)	[ff]	6.00	6.00
Profile slope deviation (µm)	[fHa]	5.00	5.00
Total profile deviation (µm)	[Ff]	8.00	8.00
Helix form deviation (µm)	[fbf]	4.00	4.00
Helix slope deviation (µm)	[fHb]	8.00	8.00
Total helix deviation (µm)	[Fb]	9.00	9.00
Normal base pitch deviation (µm)	[fpe]	7.00	7.00
Single pitch deviation (µm)	[fp]	7.00	7.00
Adjacent pitch difference (µm)	[fu]	8.00	8.00
Total cumulative pitch deviation (µm)	[Fp]	19.00	19.00
Sector pitch deviation over z/8 pitches (µm)	[Fpz/8]	12.00	12.00
Runout (µm)	[Fr]	14.00	14.00
Tooth Thickness Variation (µm)	[Rs]	8.00	8.00
Single flank composite, total (µm)	[Fi']	22.00	22.00
Single flank composite, tooth-to-tooth (µm)	[fi']	10.00	10.00
Radial composite, total (µm)	[Fi"]	17.00	17.00
Radial composite, tooth-to-tooth (µm)	[fi"]	6.00	6.00

According to DIN 58405:1972 (Feinwerktechnik):

Tooth-to-tooth composite error (µm)	[fi"]	7.00	7.00
Composite error (µm)	[Fi"]	20.00	20.00
Axis alignment error (µm)	[fp]	4.93	4.93
Flank direction error (µm)	[fbeta]	5.00	5.00
Runout (µm)	[Trk, Fr]	21.00	21.00

(Tolerances of rack following DIN 3961:1978 mit der Zähnezahl und dem Teilkreis des Ritzels berechnet)

Axis alignment tolerances (recommendation acc. to ISO TR 10064-3:1996, Quality 6)

Maximum value for deviation error of axis (µm)	[fSigbet]	17.00 (Fb= 17.00)
Maximum value for inclination error of axes (µm)	[fSigdel]	34.00

8. ADDITIONAL DATA

Exponent kappa (temperature calculation)	[ExpKappa]	0.400	
Coefficient of friction	[mum]	0.240	
Loss factor	[HV]	0.088	
Coefficient for frequency of running	[KstEDf]	1.000	
Casing surface (m²)	[Oberflache]	41.31000	
Gear power loss (W)	[PVZ]	0.271	
(Meshing efficiency (%)	[etaz]	97.886)	
Tooth root temperature (°C)	[TR]	70.0	70.0
Flank temperature (°C)	[TF]	70.0	70.0

9. MODIFICATIONS AND TOOTH FORM DEFINITION

Data for the tooth form calculation :
Data not available.
Please run the calculation in the "Tooth form" tab and open the main report again.

10. SERVICE LIFE, DAMAGE

Required safety for tooth root	[SFmin]	1.20
Required safety for tooth flank	[SHmin]	0.90
Required safety for wear	[SWmin]	1.10

Service life (calculated with required safeties):

System service life (h)	[Hatt]	10396

Tooth root service life (h)	[HFatt]	1e+006	1e+006
Tooth flank service life (h)	[HHatt]	1.217e+004	1e+006
Wear service life (h)	[HWatt]	1.04e+004	1e+006

Note: The entry 1e+006 h means that the Service life > 1,000,000 h.

Damage calculated on the basis of the required service life [H] (1000.0 h)

F1%	F2%	H1%	H2%	W1%	W2%
0.00	0.0000	8.2189	0.0000	9.6193	0.0000

Damage calculated on basis of system service life [Hatt] (10395.8 h)

F1%	F2%	H1%	H2%	W1%	W2%
0.00	0.0000	85.4424	0.0000	100.0000	0.0000

Calculation of the factors required to define reliability R(t) according to B. Bertsche with Weibull distribution; t in (h):

R(t) = 100 * Exp(-((t*fac - t0)/(T - t0))^b) %

Gear		fac	b	t0	T	R(H)%
1	Tooth root	11460	1.7	9.654e+029	1.484e+030	100.00
1	Tooth flank	11460	1.3	1.257e+008	5.988e+008	100.00
2	Tooth root	5400	1.7	9.654e+029	1.484e+030	100.00
2	Tooth flank	5400	1.3	9.014e+029	4.295e+030	100.00

Reliability of the configuration for required service life (%) 100.00 (Bertsche)

REMARKS:

- Specifications with [.e/i] imply: Maximum [e] and Minimal value [i] with consideration of all tolerances
  Specifications with [.m] imply: Mean value within tolerance
- For the backlash tolerance, the center distance tolerances and the tooth thickness deviation are taken into account. Shown is the maximal and the minimal backlash corresponding the largest resp. the smallest allowances
  The calculation is done for the operating pitch circle.
- Calculation of steel/plastic pair:
  the steel gear's strength is calculated approximately, according to DIN 3990, to obtain an indication of the service life..

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