Fundamentals of Chain Technology

WIPPERMANN

Agenda

1) Structure, terms and classification as machine element

2) Forces, torques, kinematics

3) Arrangement and mounting

4) Tribology, wear and failure mechanisms

5) Design and calculation

6) Lubrication, corrosion, coating, temperature

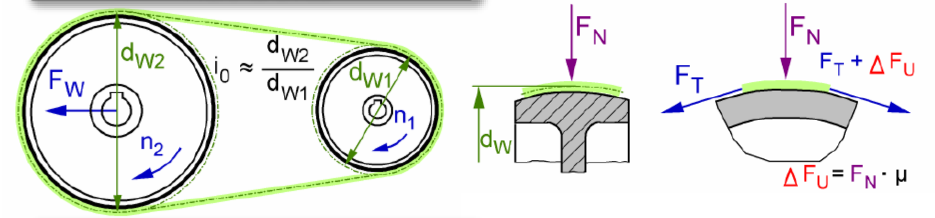
Power transmission drives

- Function of power transmission drives:
  - Power transmission (torque, rotational speed)
  - over a specific distance of axles
- Selection criteria:
  - Function, economic efficency

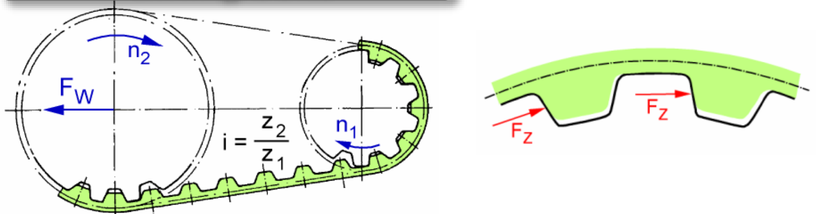
by friction

by positive fit

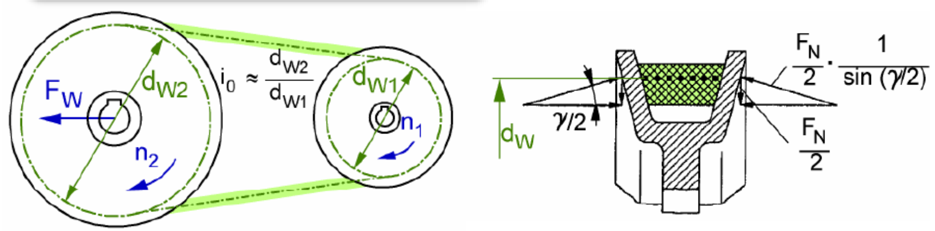
flat belts



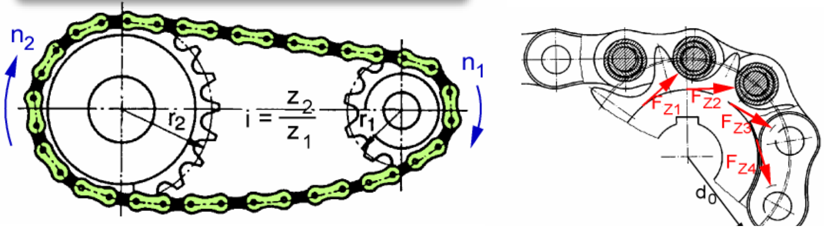
timing belts



V belts



steel-link chains



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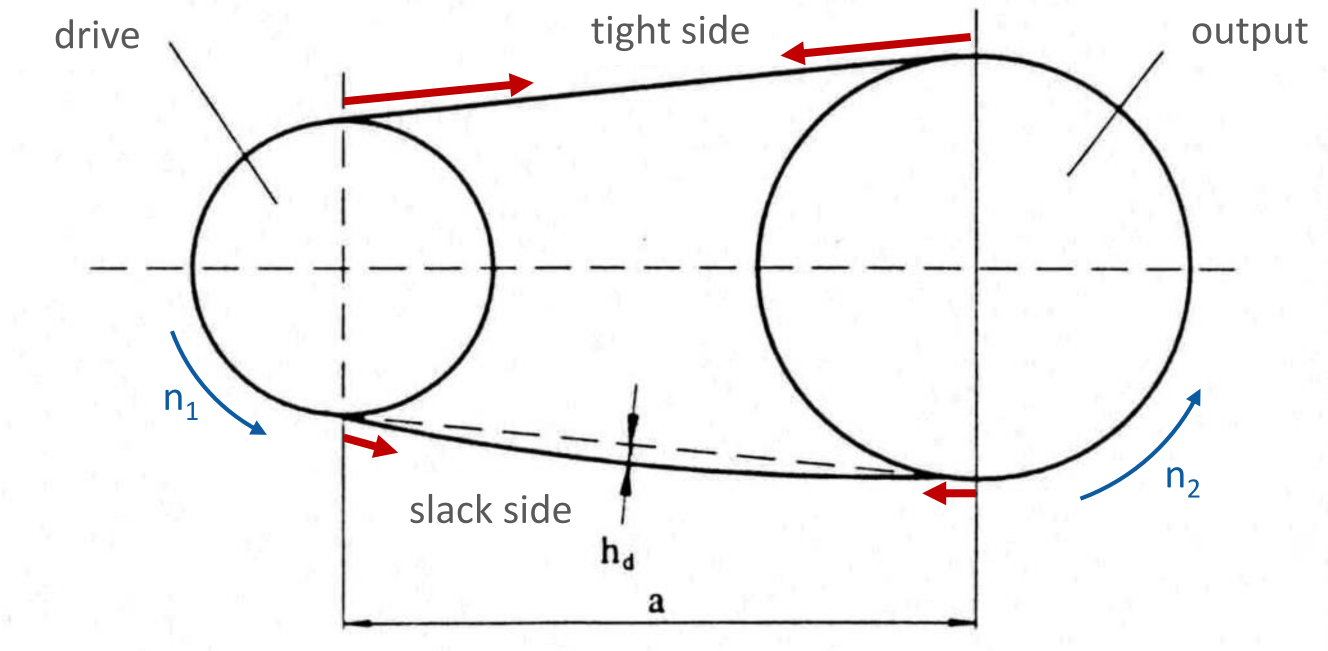
Drive chains



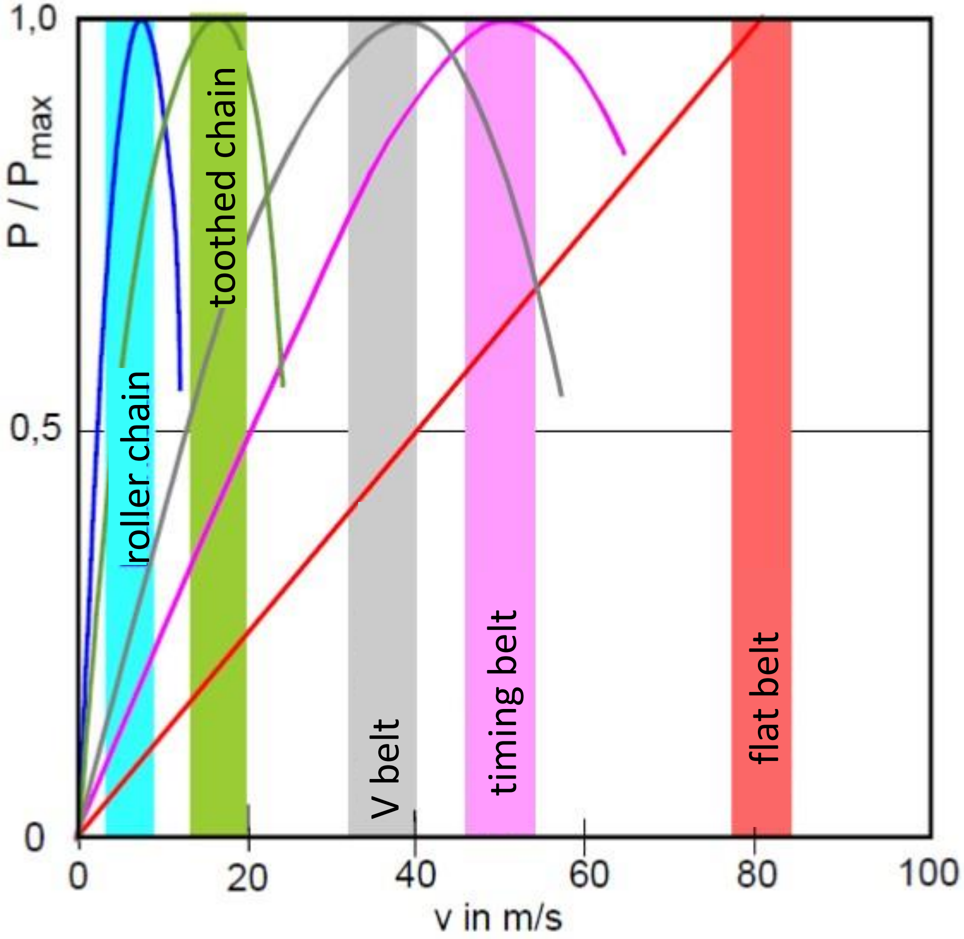
positive fit power transmission

P = T· ω (torque, rotational speed)

over a large distance of axles

Comparison of power transmission drives

- **Roller chain** performance is very good at low speeds and high loads
- For applications with high speed **belt drives** are more suitable
- All drive systems can reach a similar transferable power level, depending on their design



$$P = T \cdot \omega$$

chain belt

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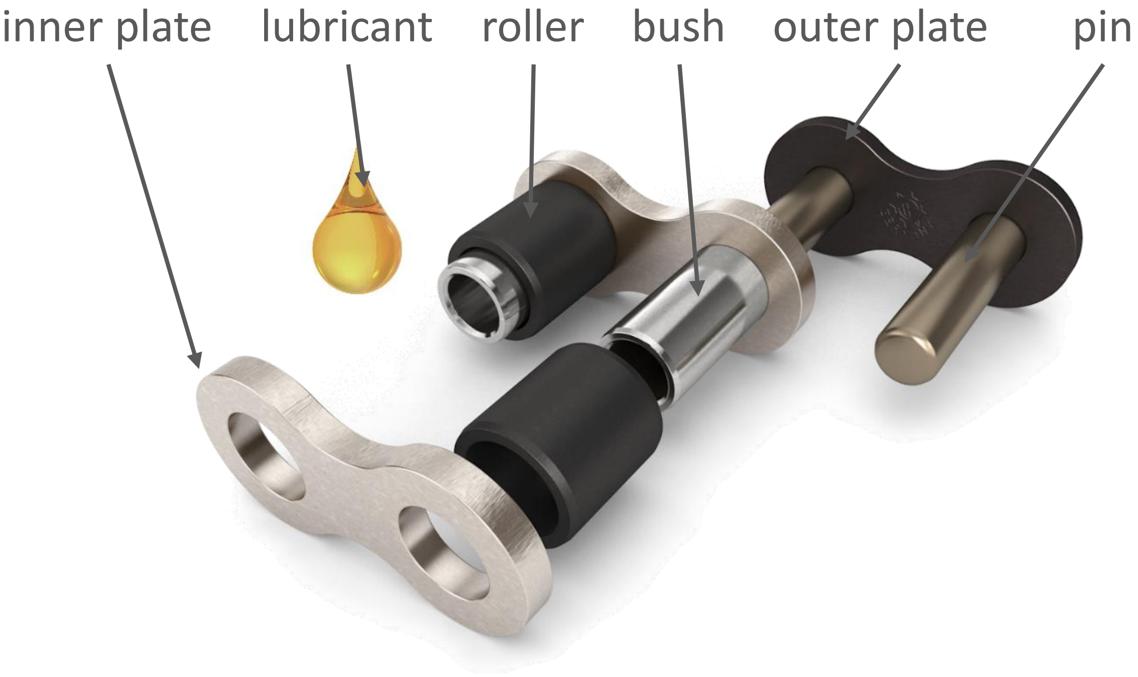
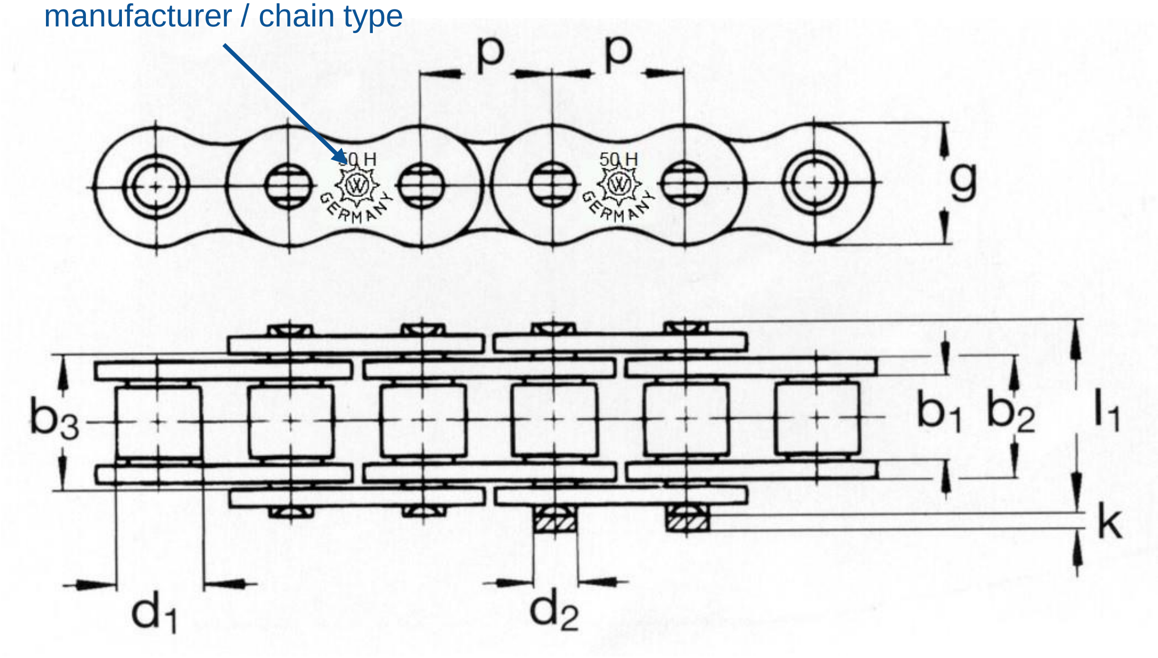
Structure of roller chains



form (waisted, straight, cranked, special…) x size x material x coating x special parts x lubrication

Roller chain dimensions ISO 606 (DIN 8187, DIN 8188)



lettering

manufacturer / chain type

p: pitch
l_1: width over pin (max)
k: projection over conn. link (max)

b_1: inner width (min)
b_2: inner link width (max)
b_3: outer plate width (min)

d_1: roller diameter (max)
d_2: pin diameter (h9)
g: plate height (max)

Chain terms

WIPPERMANN	(DIN) ISO	Design
548	16 B-1	1“ Simplex roller chain
D 548	16 B-2	1“ Duplex roller chain
652	32 B-1	2“ Simplex roller chain

→ ISO 606 (DIN 8187) „**B**ritish Standard“

→ 1/16 of pitch in Inch or ≈ roller-Ø in mm

F 254	LL 1644	1“ Leaf chain LL 4x4 lacing
F 504 U		2“ Leaf chain 4x4 works standard
548 GL (GLS DIN g-Maß)		1“ Roller chain with straight plates
548 GL MA		+ Marathon version
548 RF		1“ Roller chain stainless steel
548 RF MA		+ Marathon version
548 SF		1“ Accumulator chain

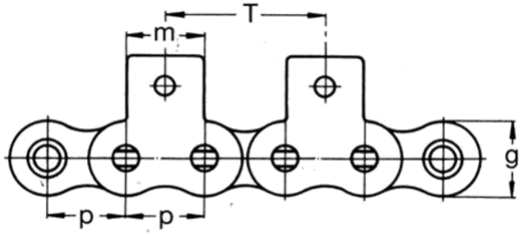
How to order - necessary information

- Chain (type, size, version)
- Length (meter or number of links, standard length 5 m)
    - Chain ends are inner links,
    - Connection link separately
    - Uneven no. of links: cranked link required

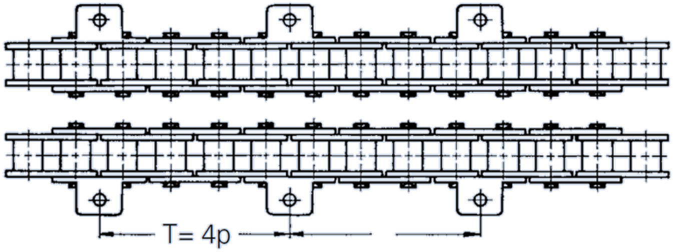
$L = X \cdot p$

- Attachment plates are usually outer plates

$T_{min} = 2 \cdot p$



- Chains in **clocked** production machinery (e.g. packaging machines) require special manufacturing tolerances to ensure their parallel run.
    - Realization by measuring and sorting of sections in classes(L = (T-1)•p)
    - Only economically for larger orders
    - Description required in the order



Chain drive: Pro and Contra

Pro

- **Wide range of applications** (drive-, conveyor- and lifting chains)
- **Implementation of multiple functions** by means of chain attachments (custom chains)
- **Reliable** (temperature, contamination, environment)
- **Positive fit drive,** no slip
- **Economical**
- **Wide power range** (pitch, simplex, duplex, triplex)
- Diverse transmission ratios
- Wide distance of axles possible (e.g. conveyor applications)
- Early indication of possible failure through chain elongation (wear)
- Easy shortening or extending
- Drive and output from both sides possible, also on several axes
- Fire safety
- High efficency
- Long lifetime
- Elasticity, damping
- No preload necessary = no static bearing load

Contra

- **Maintenance** required (re-lubrication, re-stress)
- **Chain elongation** through joint wear
- **Dynamic** through polygon effect (small number of teeth)
- Noise
- Possibly occurrence of oscillations in unfavorable designs
- Weight, centrifugal forces
- Precise alignment of shafts and sprockets necessary
- Partly chain tensioner necessary (reversing operation)
- Partly guide rails necessary (wide distance of axles, conveyor chains)
- Partly adaption of distance of axles necessary

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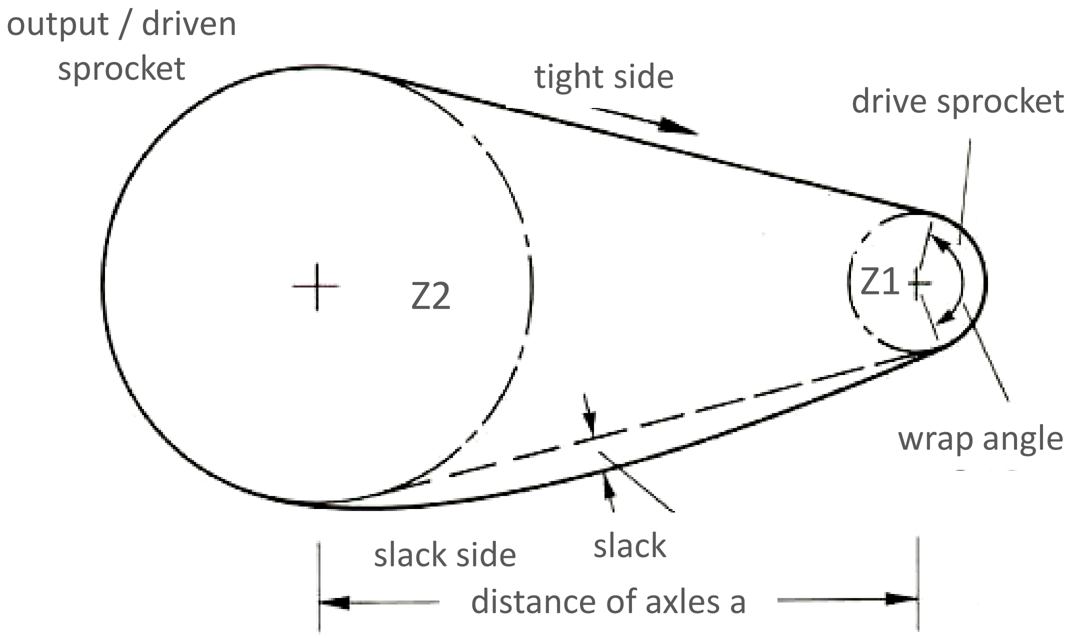
Forces, torques and transmission ratio

- Positive fit power transmission
- Fixed transmission ratio *i* according to number of teeth of the drive and output sprockets

$$i = \frac{z_2}{z_1} = \frac{n_1}{n_2} = \frac{T_2}{T_1}$$

$P_2 = T_2 \cdot \omega_2$



$P_1 = T_1 \cdot \omega_1$

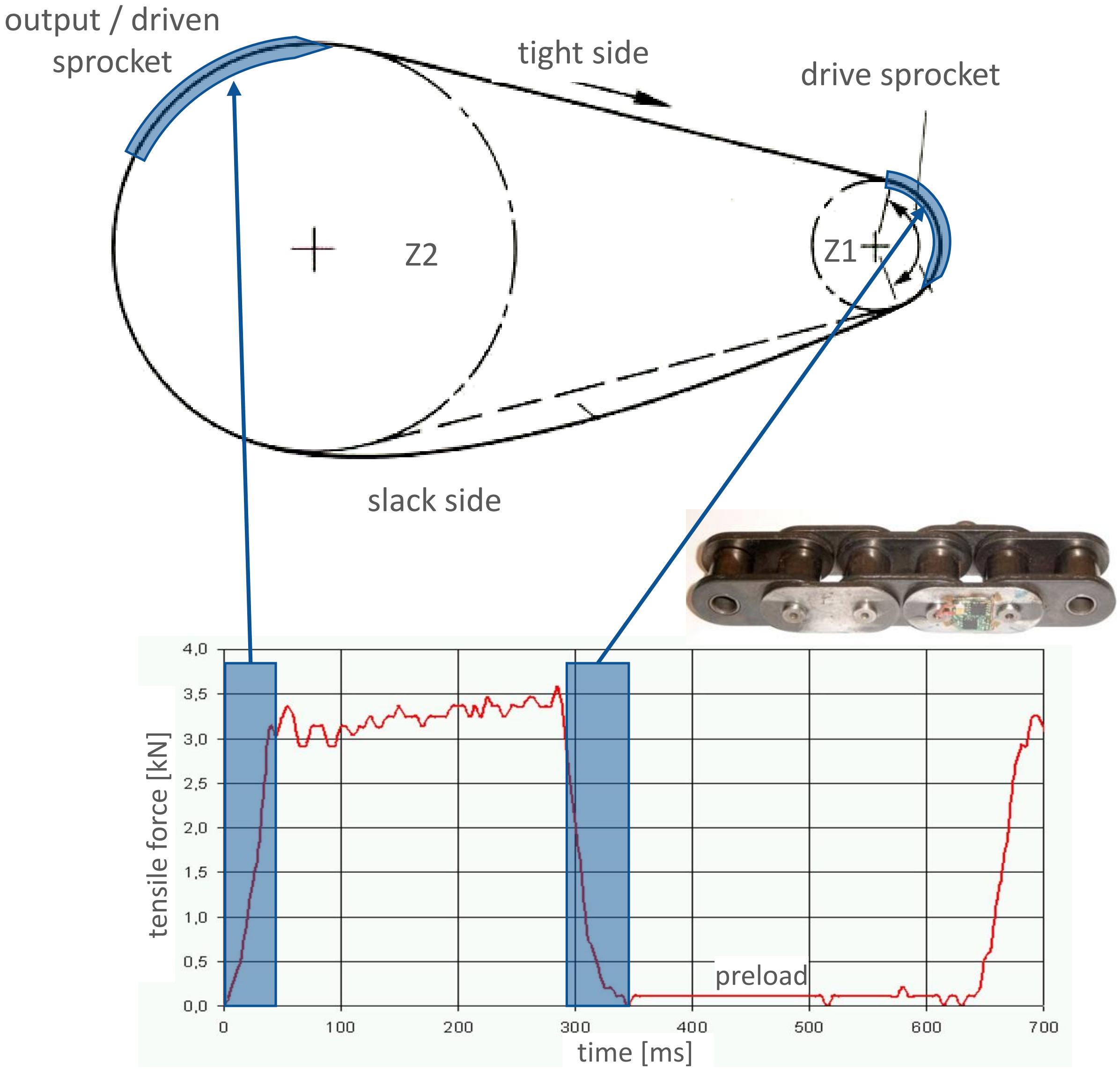
$P_2 \approx 0{,}97 \cdot P_1$

efficiency about 97%

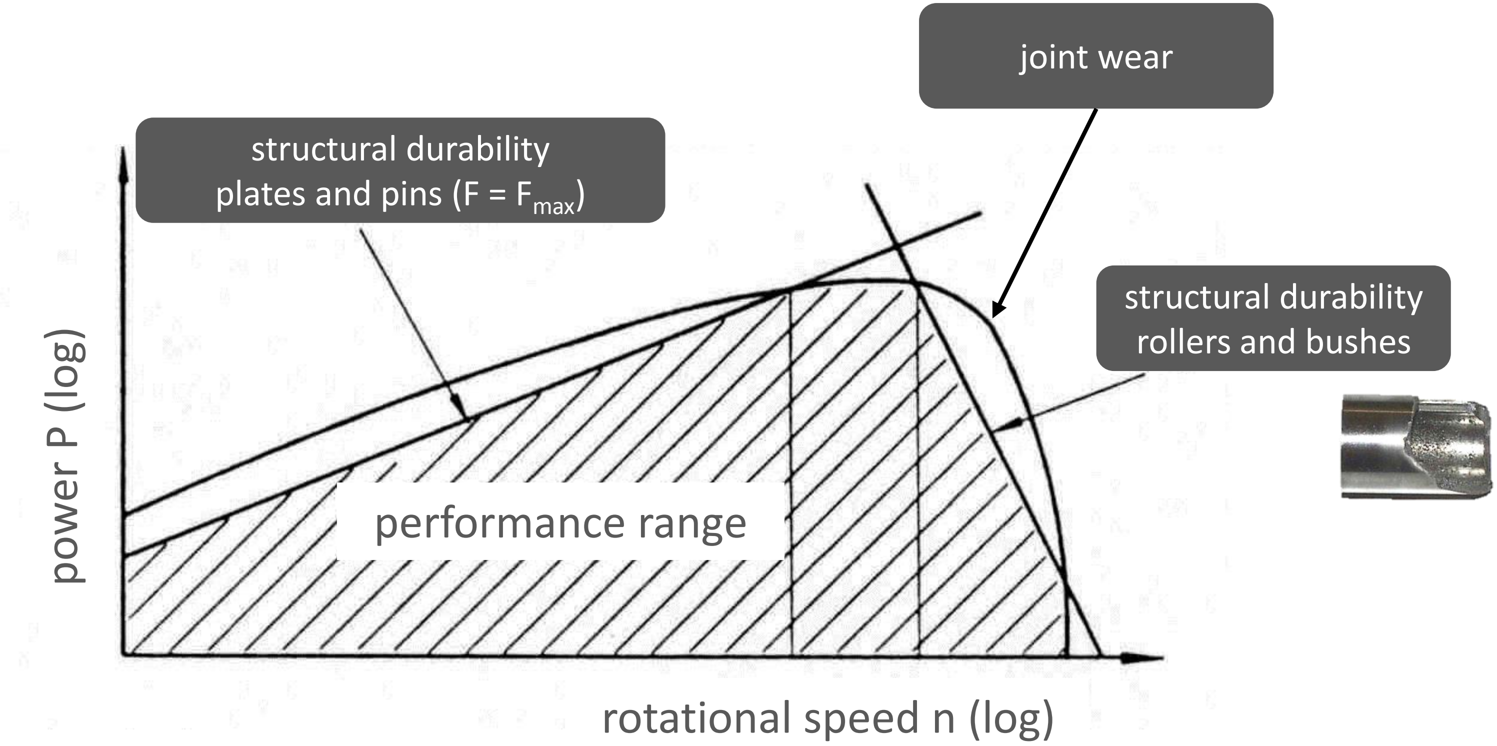
ΔP: losses through: heat, noise, wear

Power transmission in the application

- Torque induction is not equally distributed of the whole wrap angle
- Normally the load is induced over the first (approx. 5) teeth
- The higher the wear induced elongation of the chain the less teeth carry the load



Limits of power transmission



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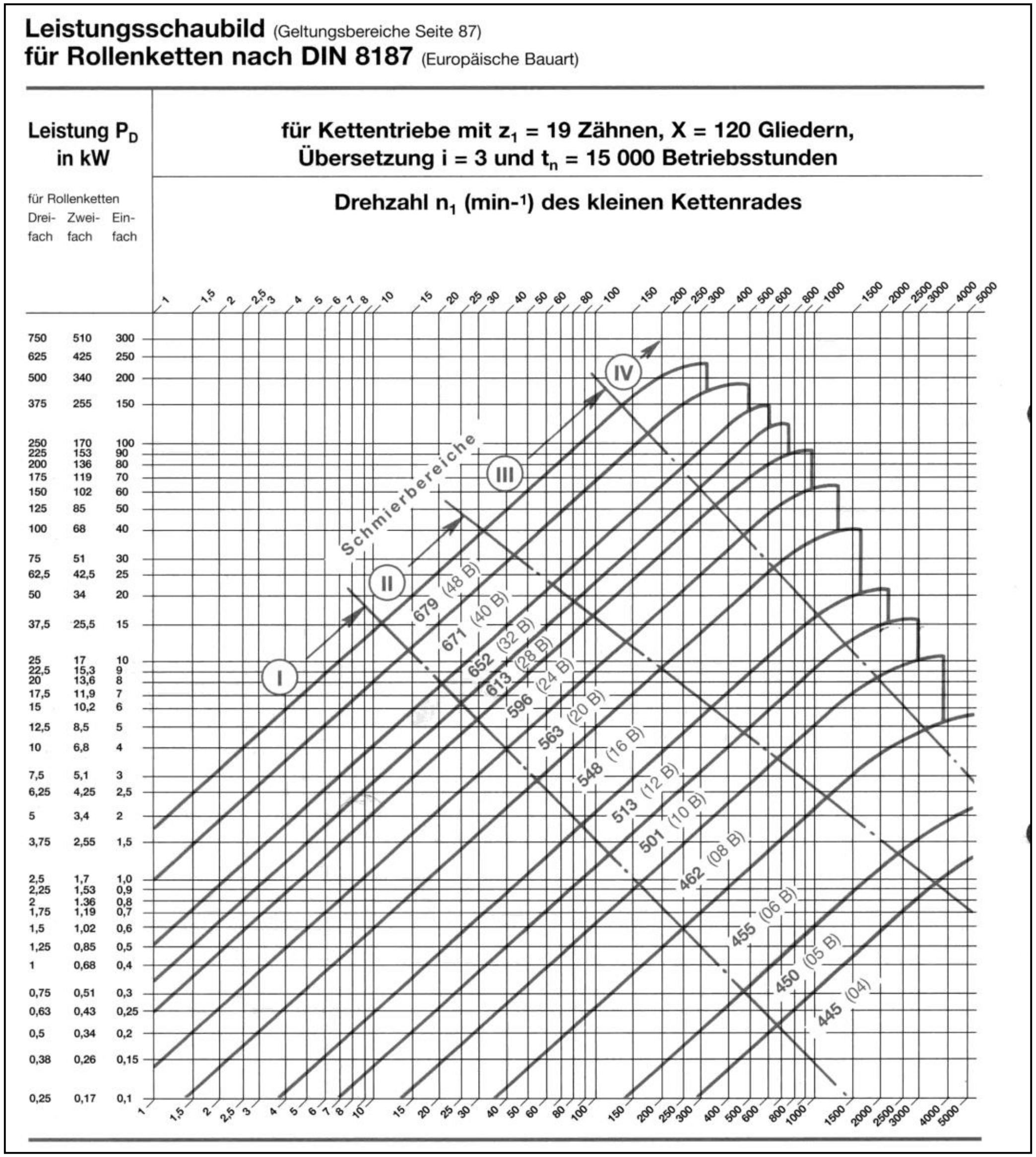
Performance range (example)

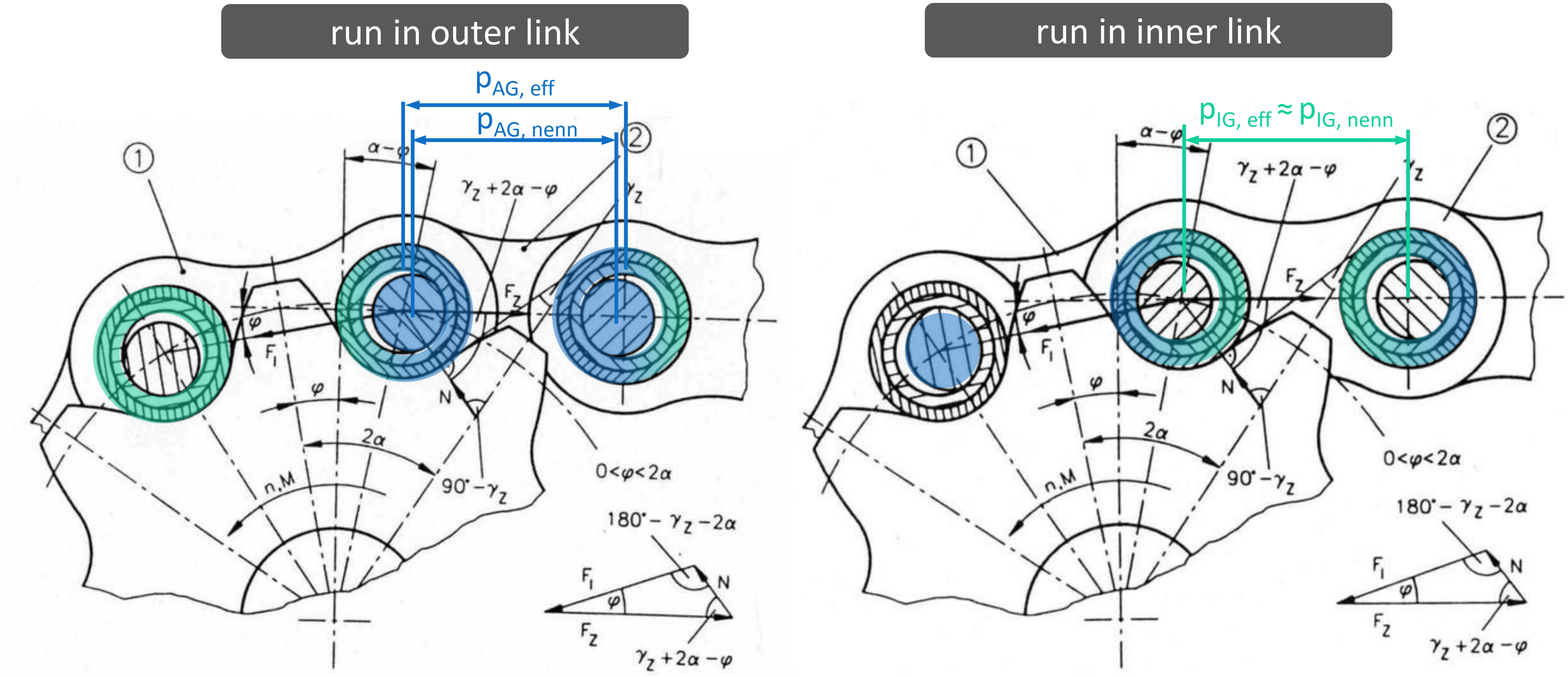


Leistungsschaubild (Geltungsbereiche Seite 87)
für Rollenketten nach DIN 8187 (Europäische Bauart)

Reference conditions

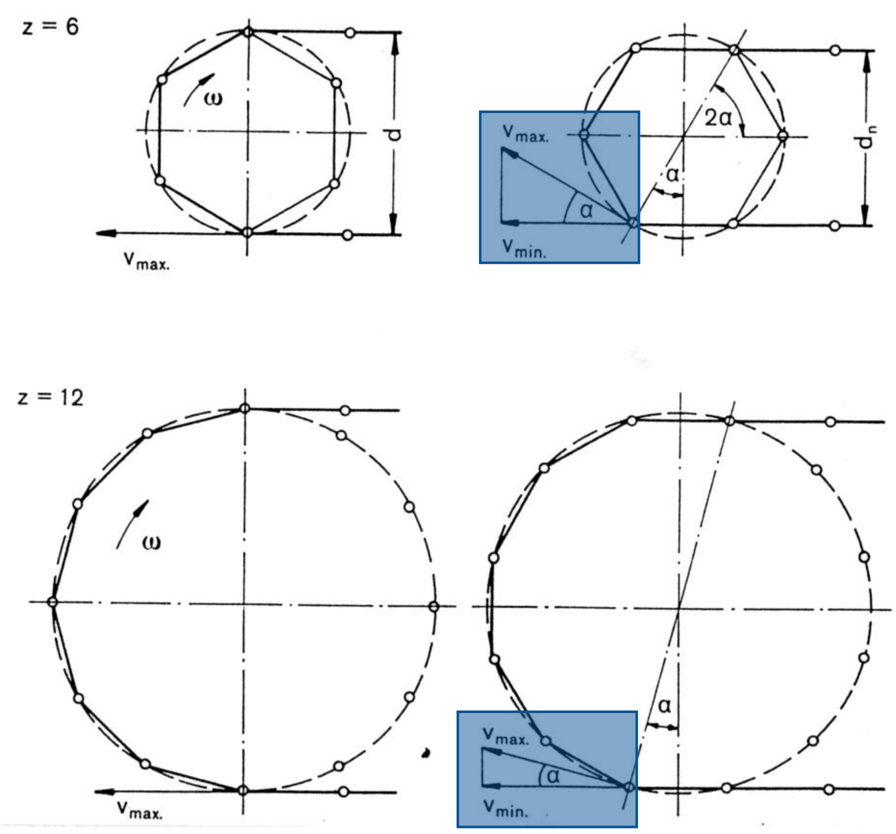
- L_V = 15.000 hours of operation
- X = 120 chain links
- z_S = 19
- i = 3
- temperature = -5 ... +70°C
- sprockets alligned
- no impacts
- clean environment and sufficient lubrication

Chain run in into the sprocket



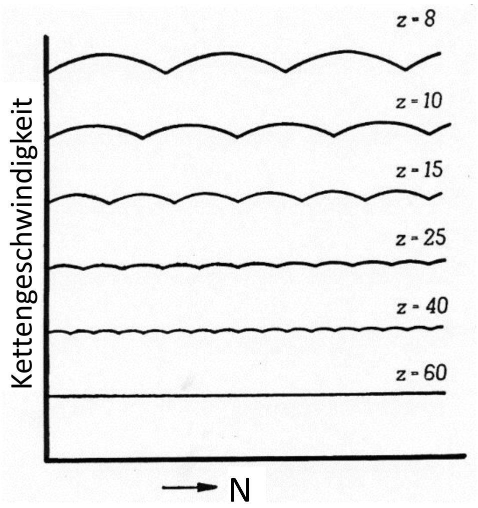
- Inner- and outer links have different hole distances (manufacturing pitch). The outer link pitch is shorter.
- By means of the clearance between pin and bushing, which is eliminated when force is applied, the differences in inner and outer link manufacturing pitches is compensated. The effective pitch of inner and outer link is the same in new state.
- Wear of pin and bushing increase the effective pitch of the outer link. The inner link pitch remains nearly the same.
- To prevent transfer of this uneven wear on the sprocket **uneven number of teeth** should be used.

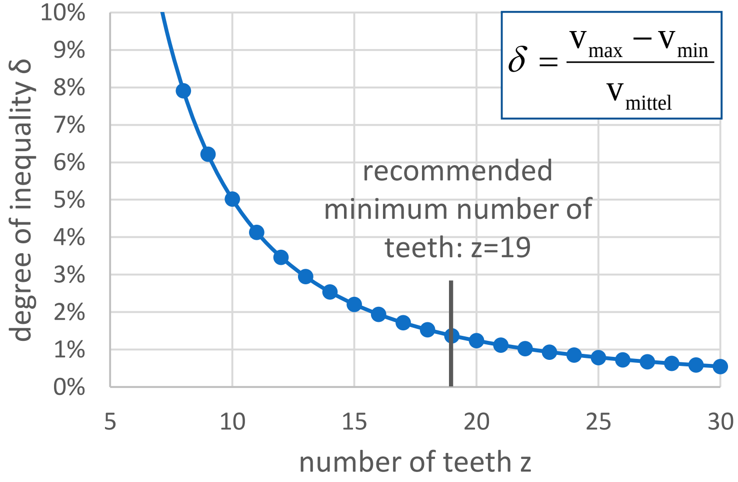
Polygon effect



$$v_{max} = \frac{p \cdot n \cdot \pi}{\sin 180°/z}$$

$$v_{min} = \frac{p \cdot n \cdot \pi}{\tan 180°/z}$$

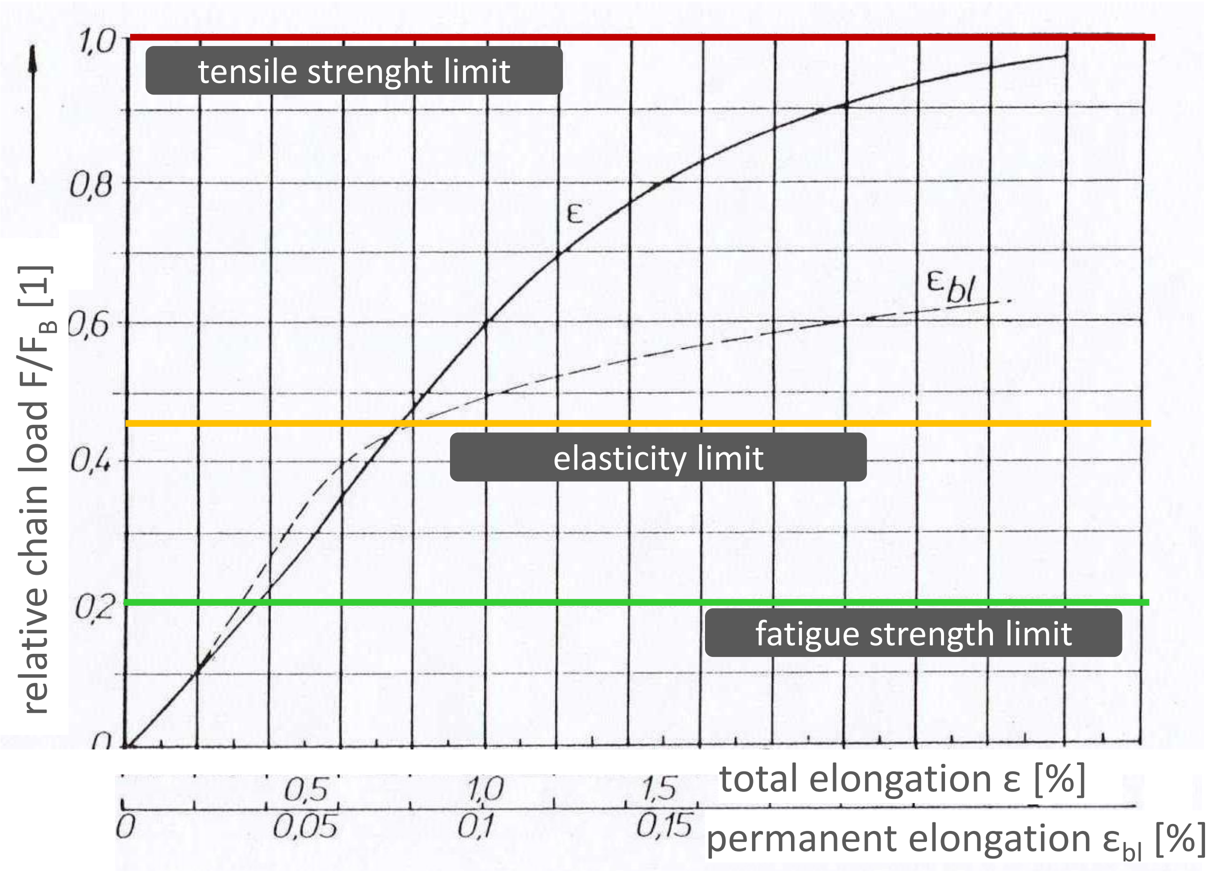




$$\delta = \frac{v_{max} - v_{min}}{v_{mittel}}$$

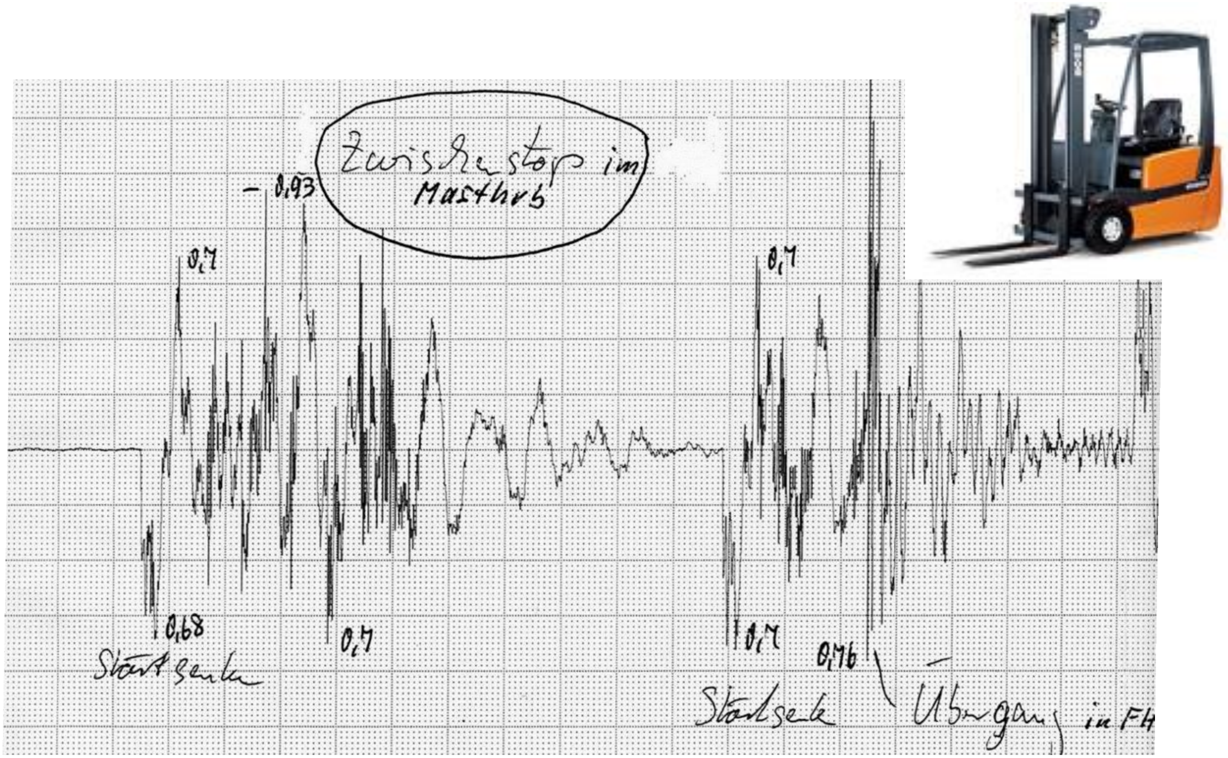
Load limits

- Usually in chain applications a safety factor of S > 7 is designed. Hence chains are operated in fatigue strength range. For lifting applications the safety factor should be at least S > 10.
- At loads higher than about 40% of tensile strength settling effects and also substantial plastic deformation occurs.



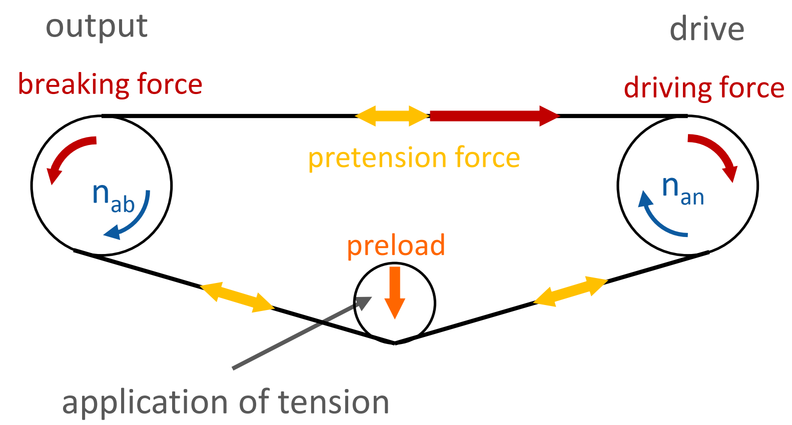
Dynamic load during operation

- Usually chains are stressed with alternating loads during operation .
- These loads result for drive chains e.g. from the continuous change of the link between tight side and slack side.
- In common applications the chain is stressed additionally by dynamic forces coming from accelerations or loading events. The designer often does not know the precise height of these forces.
- E.g. in case of a forklift truck driving over bumps can cause very high loads, as can be seen below.



Pretensioning of chain drives

Drive in steady state condition



output

drive

breaking force

driving force

pretension force

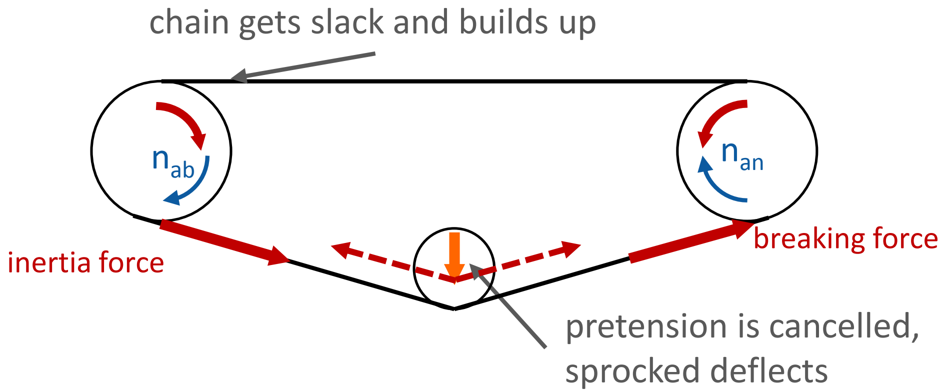
n_{ab}

n_{an}

preload

application of tension

Decelleration



chain gets slack and builds up

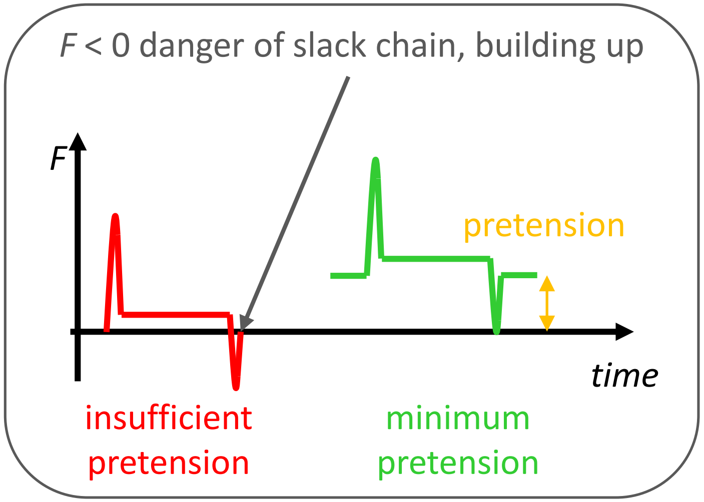
n_{ab}

n_{an}

inertia force

breaking force

pretension is cancelled, sprocked deflects

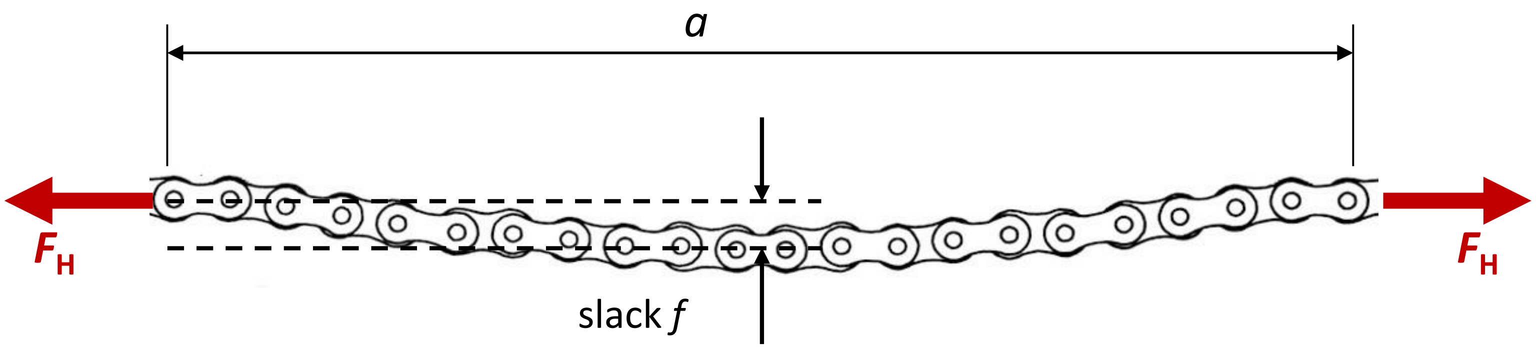


F < 0 danger of slack chain, building up

insufficient pretension

minimum pretension

Slack and pretensioning



$$f \approx \sqrt{\left(\frac{a+\Delta l}{a}-1\right)\cdot\frac{3\cdot a^2}{8}}$$

holding force $F_H = \frac{q \cdot g}{f} \cdot \frac{a^2}{8}$
(horizontal)

Δl	chain elongation
a	distance of axles / free chain length
Δq	weight per m chain

Example: Chain 16 B-1 with distance of axles a = 997mm and z1 = z2 = 19

	Nominal length	**0,1% elongation**	**1% elongation**	**2% elongation**	**3% elongation**
Slack f	none	30 mm	96 mm	136 mm	167 mm
Holding force F_H	infinity	107 N	34 N	24 N	20 N

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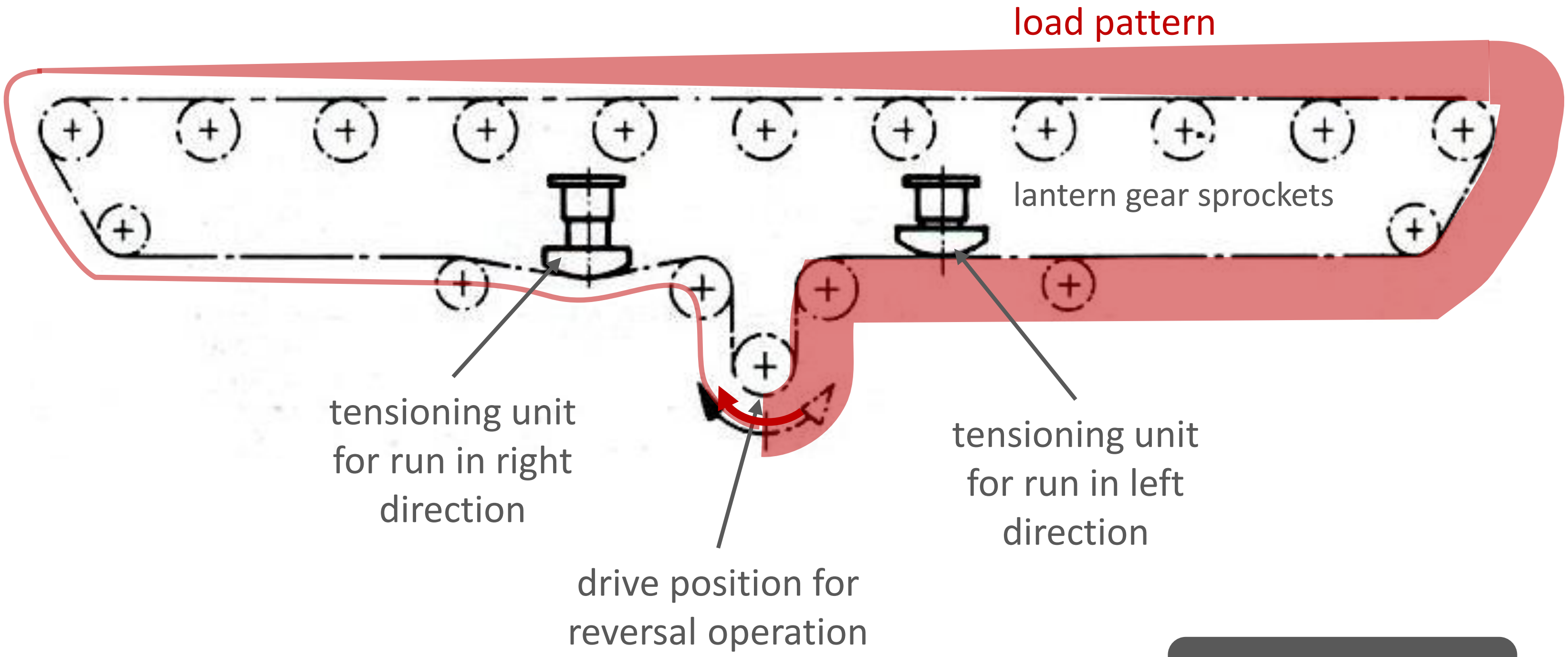
Drive and preload unit position

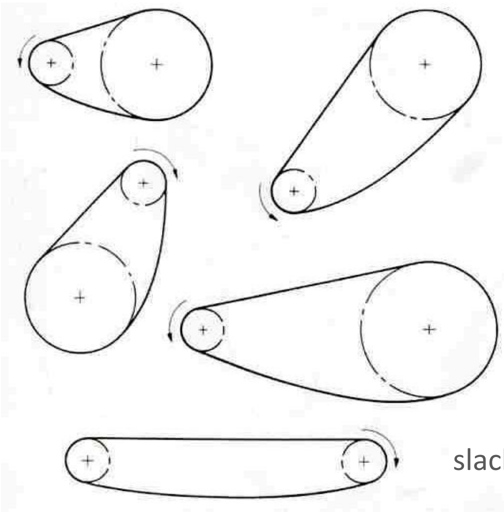
- Drive and tensioning unit should be arranged in a way that there is always a preload unit in the slack side of the chain drive. Also in case of reversal operation.



4 deflections under full load

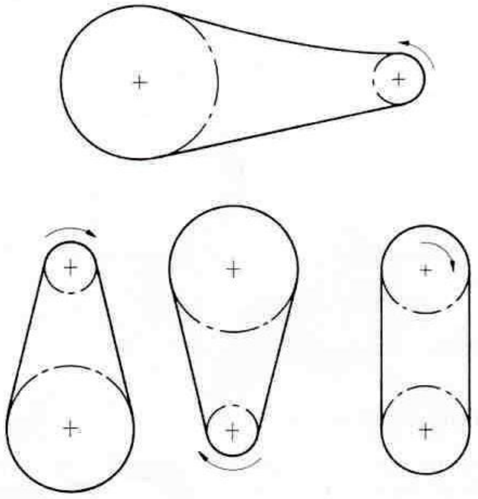
Chain drive configurations

favourable



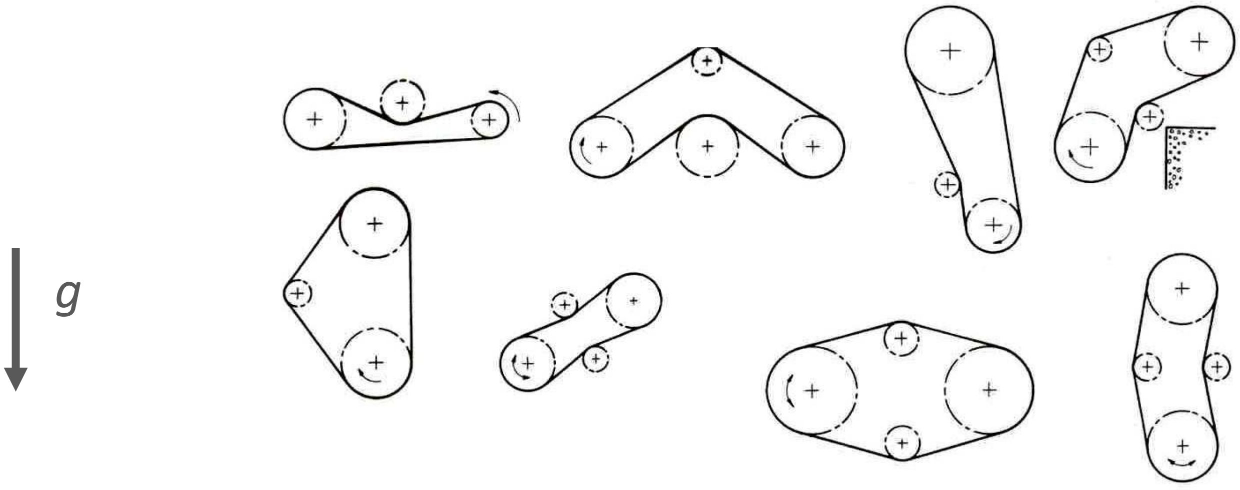
slack side down

less favourable



small sprocket up

chain tight

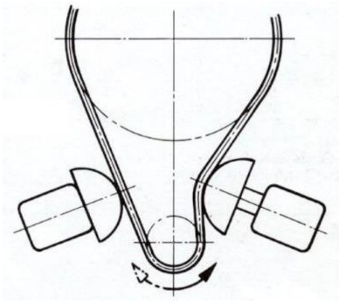


tensioning wheel with
3 teeth in slack side

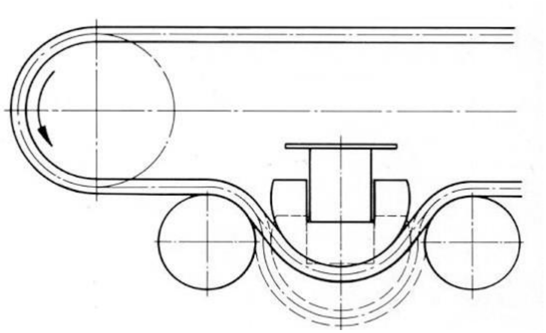
Tensioning and guiding

Wippermann recommends:

Murtfeldt Kunststoffe

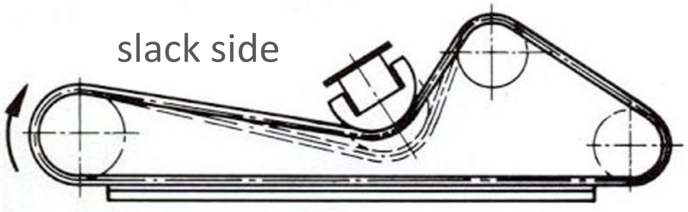


reversal



maximum use of shift range

slack side



Shortening and extending

Shortening

uneven number of links

up to a pitch
of 19,05 mm

separate

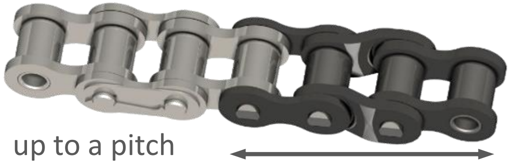
Nr. 11 Nr. 15

pitch as of 25,4 mm

separate

Nr. 12

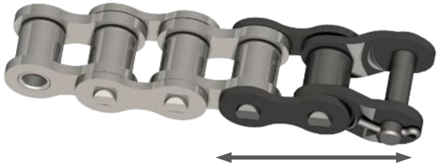
even number of links



up to a pitch
of 19,05 mm

separate

Nr. 11 Nr. 4



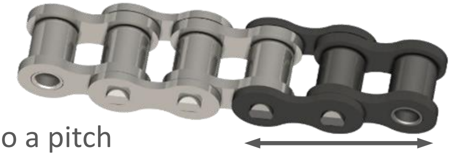
pitch as of 25,4 mm

separate

Nr. 111

Extending

uneven number of links



up to a pitch
of 19,05 mm

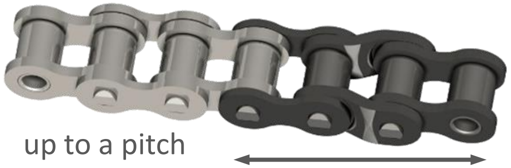
separate

Nr. 11 Nr. 15

pitch as of 25,4 mm

Nr. 12

even number of links



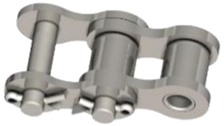
up to a pitch
of 19,05 mm

separate

Nr. 11 Nr. 4 Nr. 11 Nr. 4

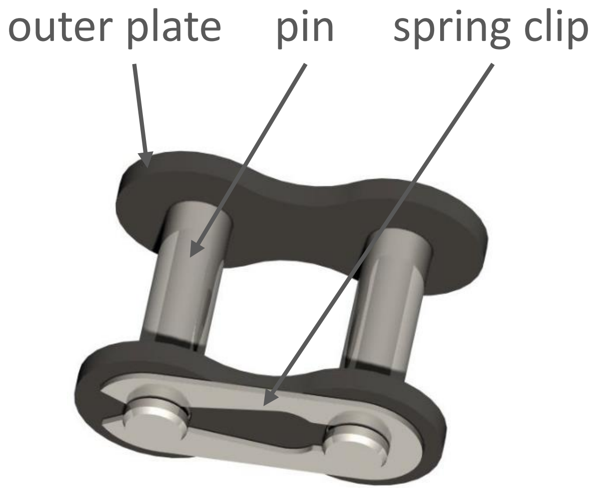
pitch as of 25,4 mm

separate

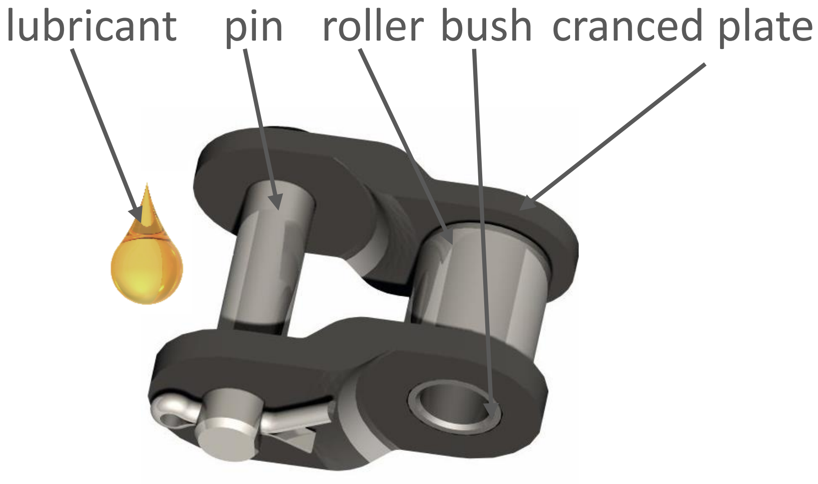


Nr. 111 Nr. 4

Structure of connection links



No. 11: Spring clip connection link



No. 12: Single cranked link

Connection links

Nr. 4 (B):
inner link

Nr. 7 (A):
outer link
(to be riveted)

Nr. 11 (E):
spring clip
connecting link

Nr. 111 (S):
connecting link
with cottered pins

Nr. 12 (L):
single cranked link
with cottered pins

Nr. 15 (C):
double cranked
link

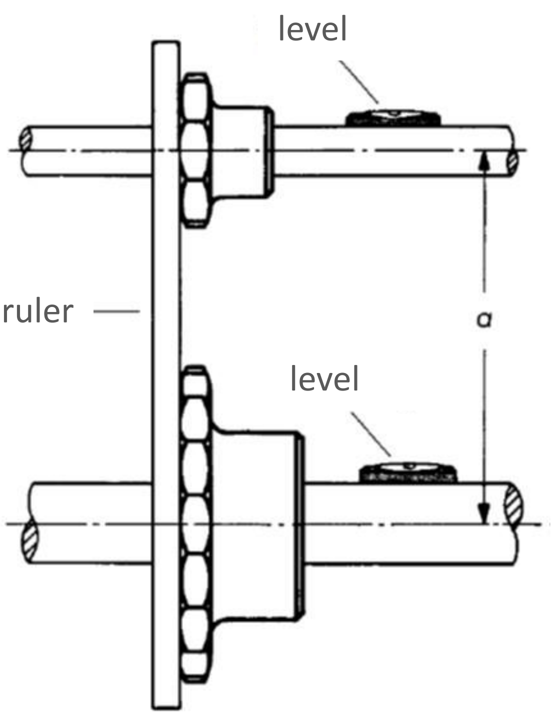
running direction

Mounting tools

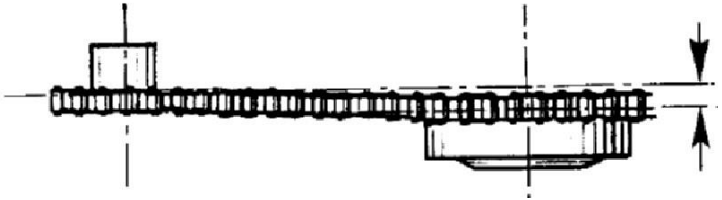
chain breakers

chain pullers

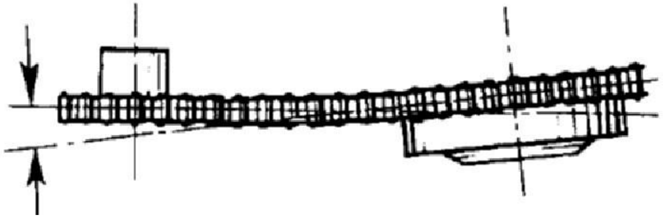
Sprocket alignment



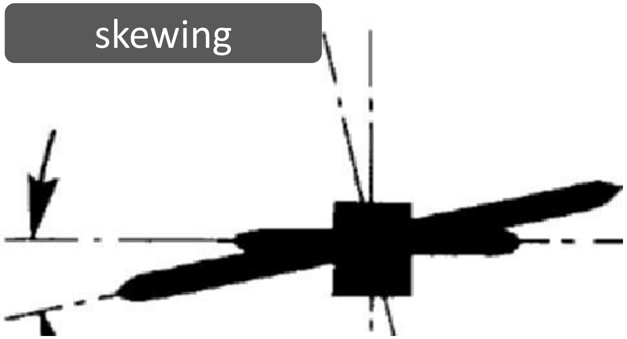
lateral offset



tilting



skewing



Alignment errors - damage patterns

Pin

- skewed wear due to non parallel axles

Inner plate

- wear due to lateral offset

Roller

- skewed wear due to non parallel axles

Sprocket

- worn edges due to lateral offset
- irregular wear due to even number of teeth

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Service life of roller chains

Wear

Chain elongation due to wear in joint (abrasion)
→ function can be restricted or not fulfilled
→ reduced cross section and load capacity

Pin roller chain

Pin leaf chain

Break

Fatigue failure
(Material-) fatigue of plates, pins, bushes

Overload fracture
Failure due to load exceeding material breaking stress

Corrosion

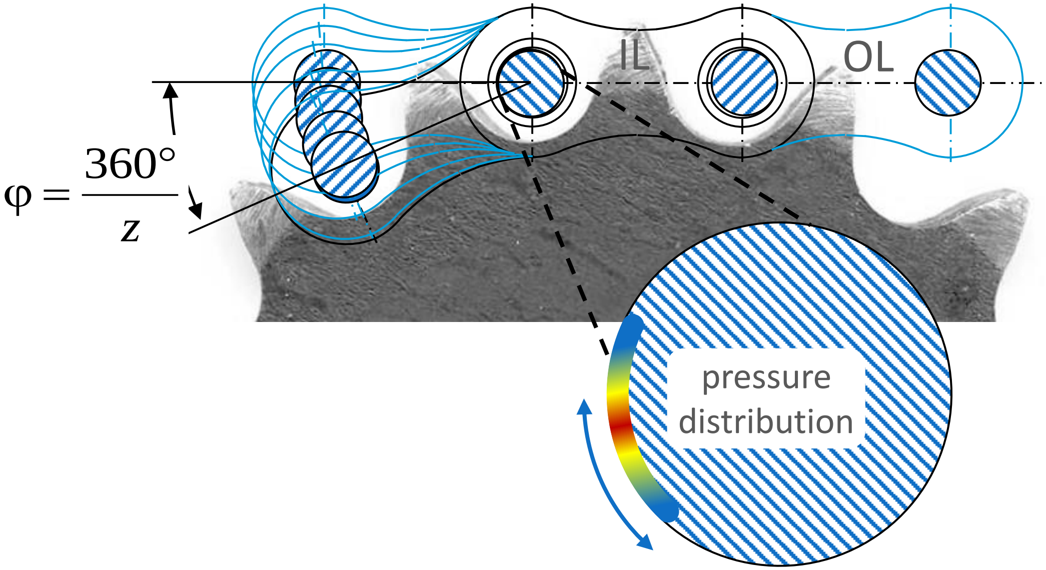
Loss of material
→ reduced cross section, reduced strength
Stiffness
→ friction
Abrasive debris
→ wear

Application and mounting errors

Mounting failure and bad machine design
→ crash
→ one-sided load
Bad maintenance, dirt
→ wear

Chain joint mechanics

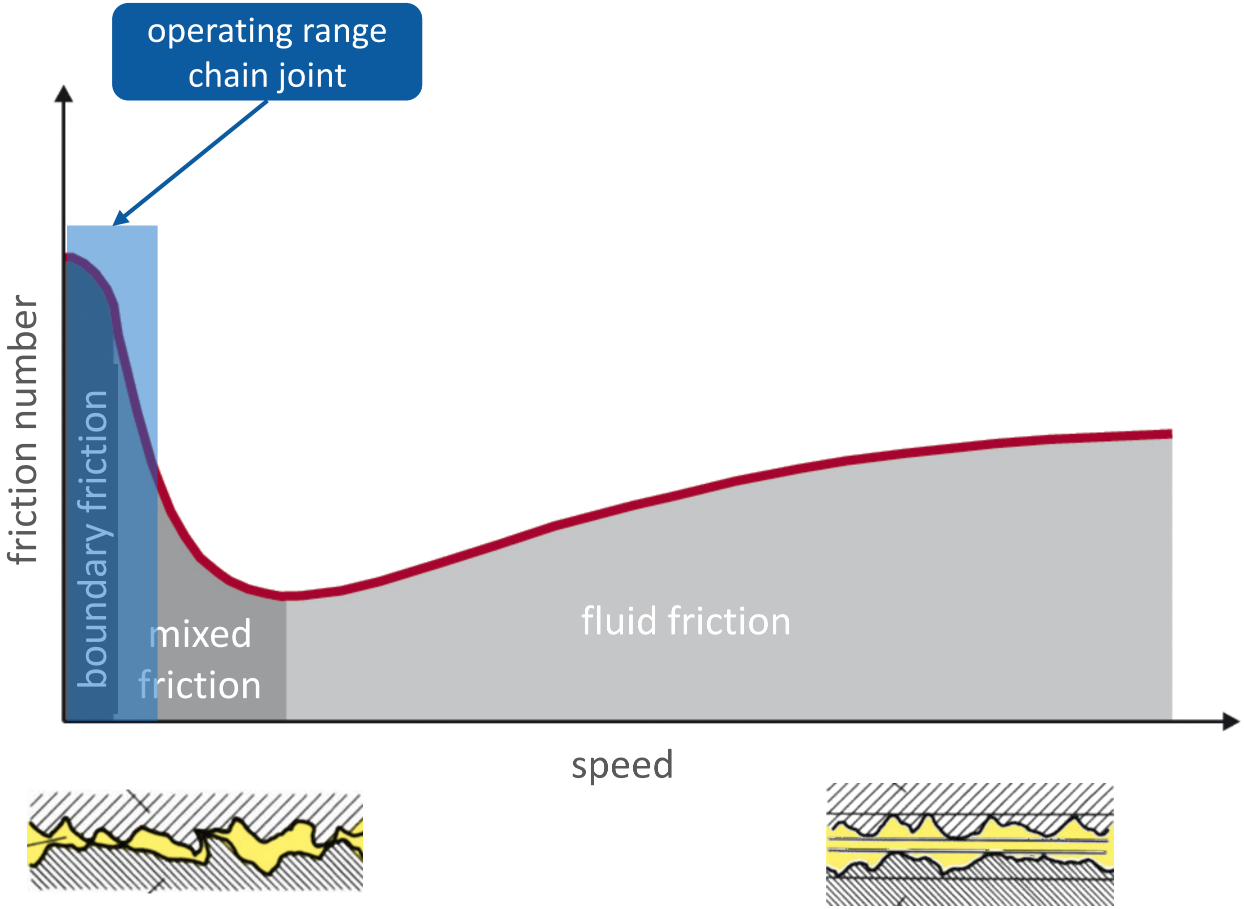
Critical section: contact pin - bush



- oscillating swivel movement
- low sliding speeds
- bad lubrication
- additional impact loads
- bad accessibility (re-lubrication)

→ static and mixed friction

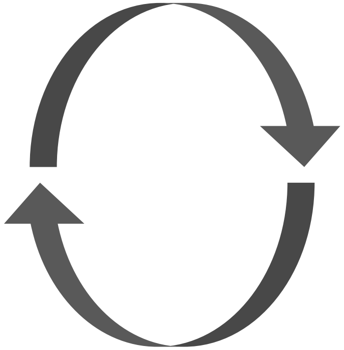
Mixed and boundary friction



Tribosystem chain joint

chain lubricant

basic body: pin

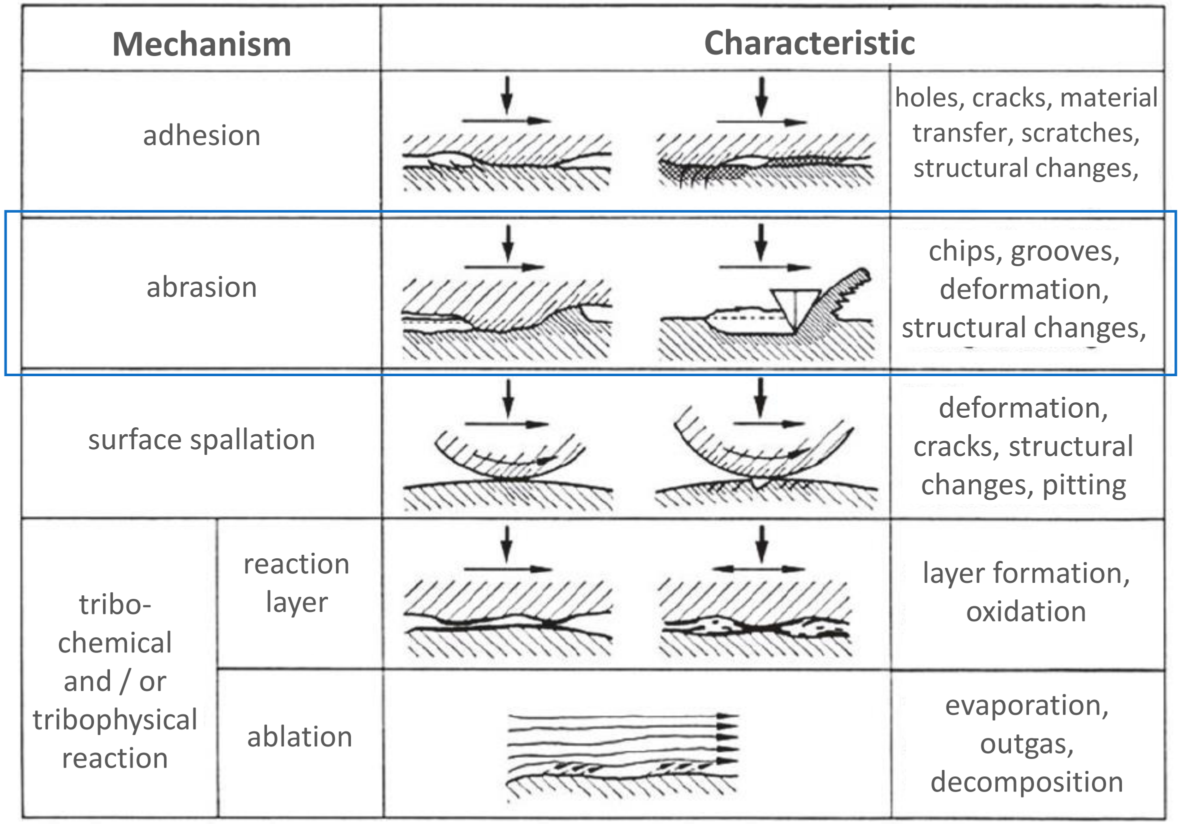


antibody: bush

environment

Wear and failure mechanisms

Wear mechanisms under tribologically load (wear)



Mechanism		Characteristic	
adhesion			holes, cracks, material transfer, scratches, structural changes,
abrasion			chips, grooves, deformation, structural changes,
surface spallation			deformation, cracks, structural changes, pitting
tribo-chemical and / or tribophysical reaction	reaction layer		layer formation, oxidation
	ablation		evaporation, outgas, decomposition

Wear and failure mechanisms

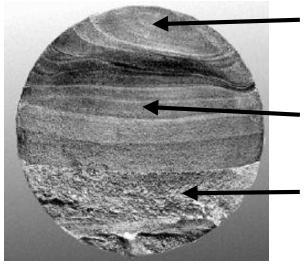
Failure mechanisms under mechanical load (break)

overload fracture

plastic deformations
rough surface

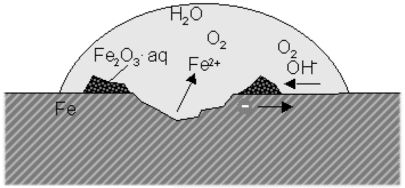
fatigue fracture

no deformations
lines of rest

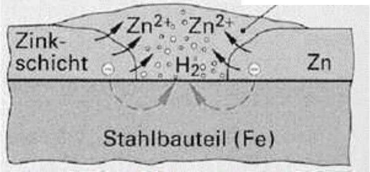


Wear mechanisms under tribochemical stress (corrosion)

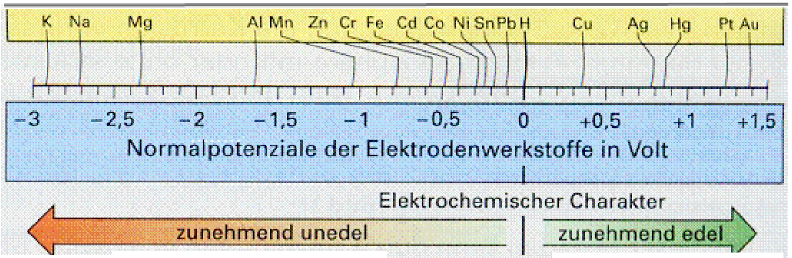
el. chem. corrosion



el. chem. corrosion with metal reaction partner



electrochemical series

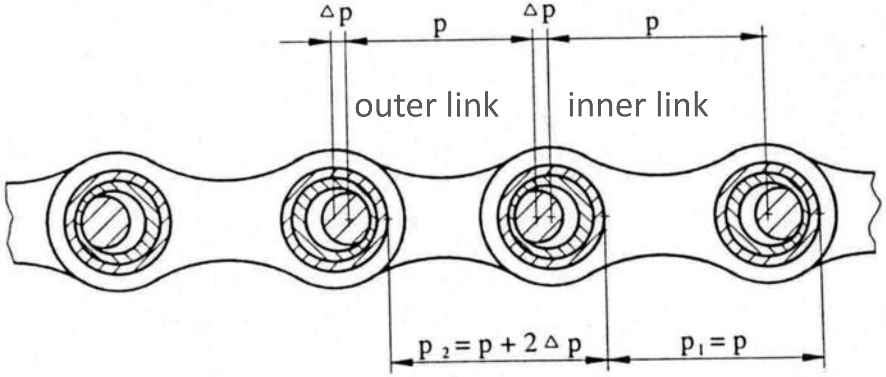


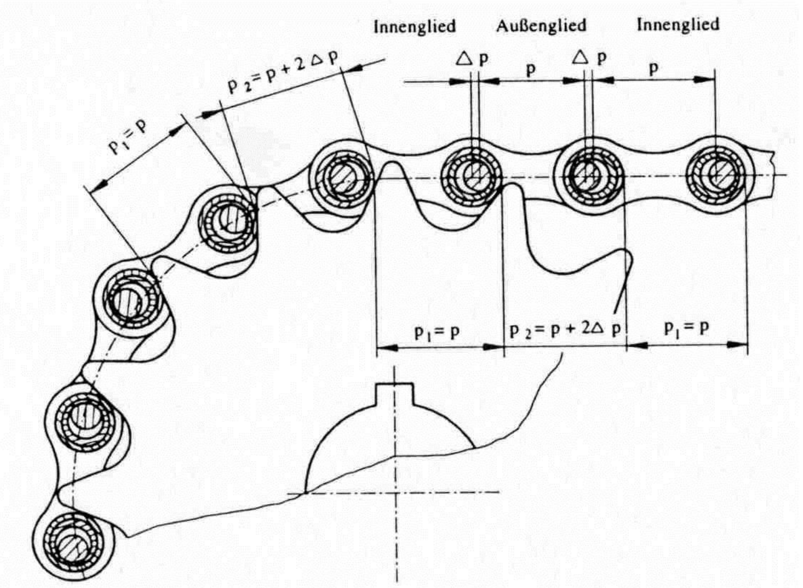
sacrificial anode

unprecious metal

precious metal

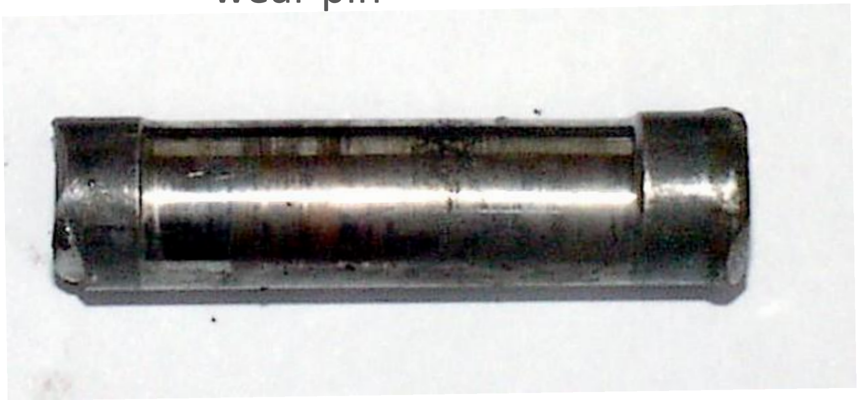
Effects of wear induced chain elongation



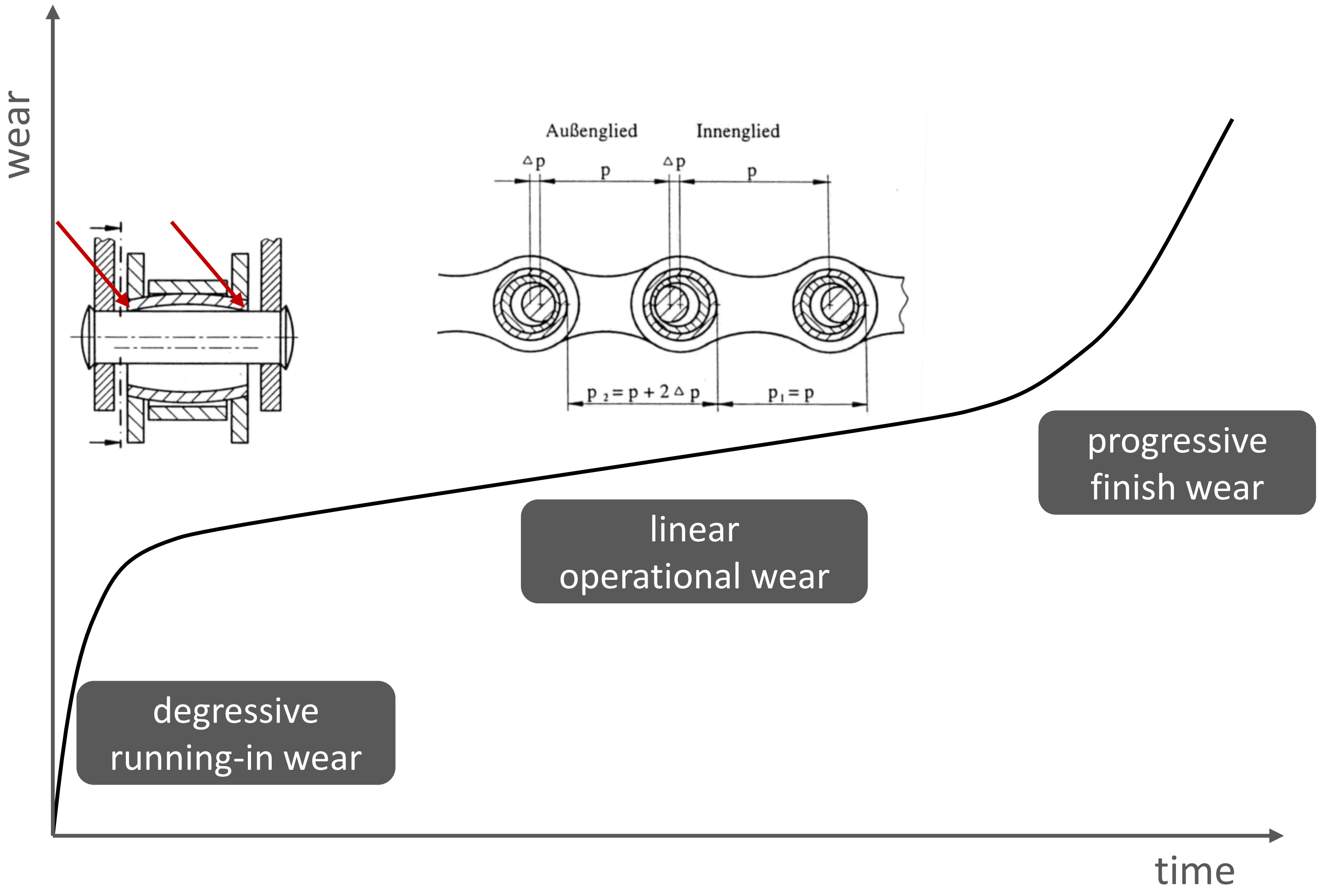


wear bush

wear pin



Abrasion curve



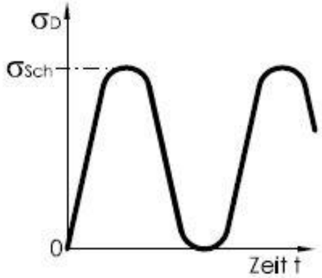
degressive running-in wear

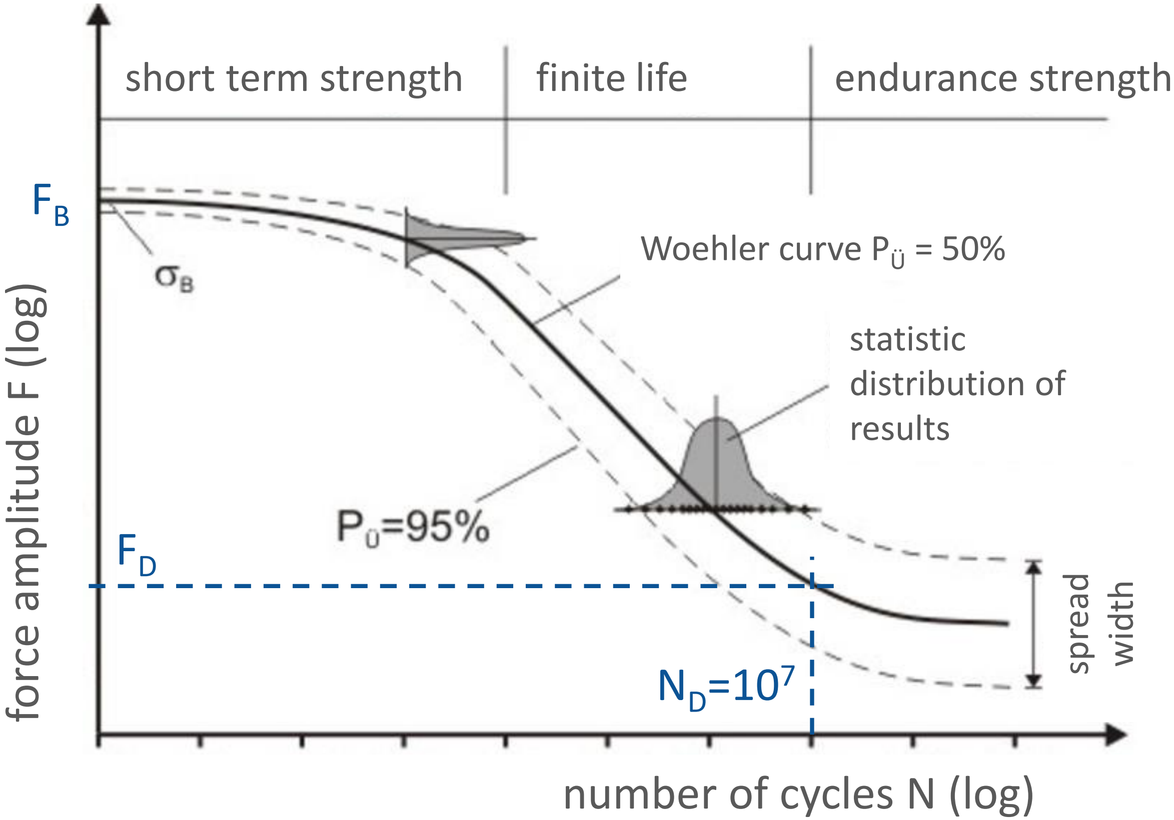
linear operational wear

progressive finish wear

Fatigue strength in Woehler diagram

- Chains operate usually under alternating loads
- For loads higher than it`s endurance limit (F_D) this will cause fatigue of the material and lead to limited lifespan



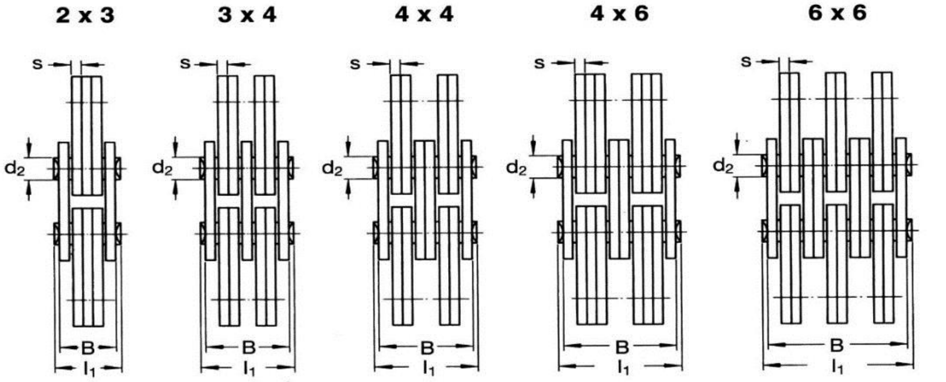


Test der dynamischen Belastbarkeit im Pulsator, Schwingfrequenz 50-100Hz

Endurance depending on number of strands

- Due to manufacturing tolerances not all parallel plates will carry the same load. The endurance load is limited by the plate which is loaded highest.
- With an increasing number of strands / parallel plates the endurance limit decreases compared to breaking load.
- Hence it does not make sense to build roller chains with more than 3 strands or leaf chains with more than 8 plates

$$\frac{\text{endurance load } F_D}{\text{breaking load } F_B}$$



Failure mode: corrosion

- Loss of material due to corrosion
  - Cross section / bearing area is reduced

- Jamming
  - Loss of functionality
  - Increased friction causes heavy wear

- Abrasive effect of rust debris
  - FeO acts like abrasive grits→ heavy wear

Failure mode: application failure

bad alignment

worn sprockets

external causes

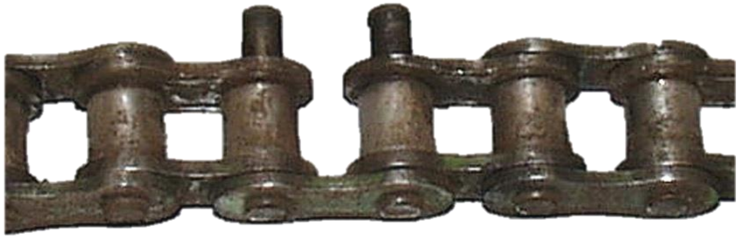
Lasche - angelaufen

no maintenance (replacement) of sprockets

crash

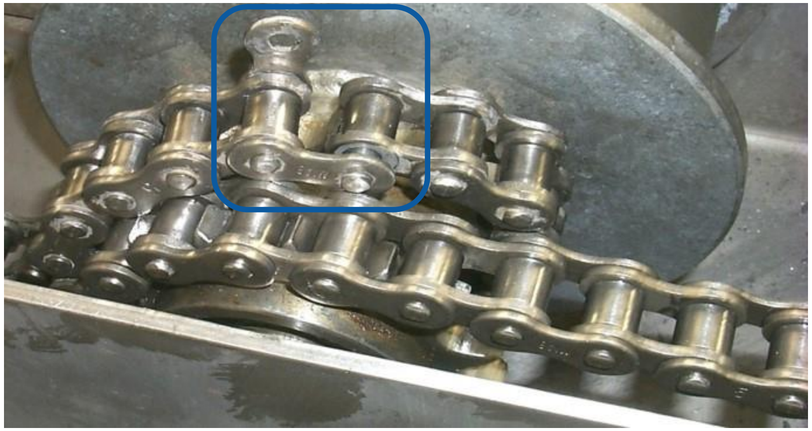
bad maintenance

roller - skewed wear

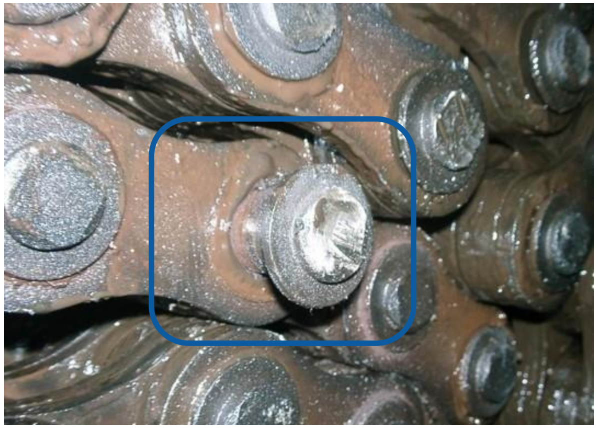


insufficient lubrication, dirt

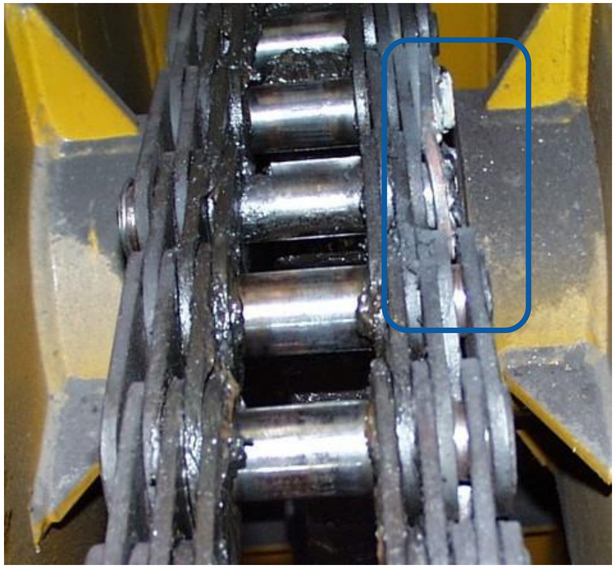
Failure mode: chain (dis-)assembly and other mistakes



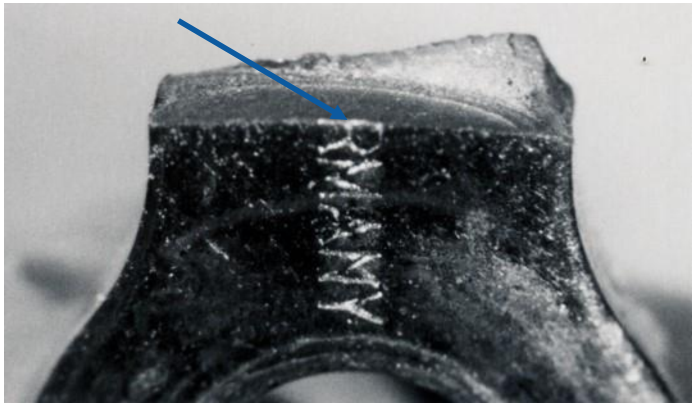
disassembled plate



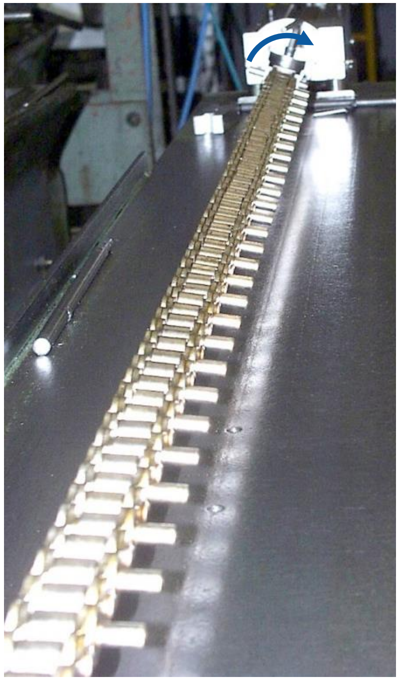
disassembled pin



missing plate



notch effect of lettering



chain twist

Limits for chain use

- **Adjustable distance of axles**
  - bis 16 m/s: max. 3 % elongation
  - über 16 m/s: max. 1,5...2 % elongation

- **Fixed distance of axles**
  - up to 4 m/s: max. 1,5 % elongation
  - over 4 m/s: max. 0,8 % elongation

- **Sprockets > 67 teeth**
  - all: max. 200/z in %
  - respectively above value if smaller

→ Chain and sprockets should be replaced if elongation has reached its limit

Agenda

1) Structure, terms and classification as machine element

2) Forces, torques, kinematics

3) Arrangement and mounting

4) Tribology, wear and failure mechanisms

5) Design and calculation

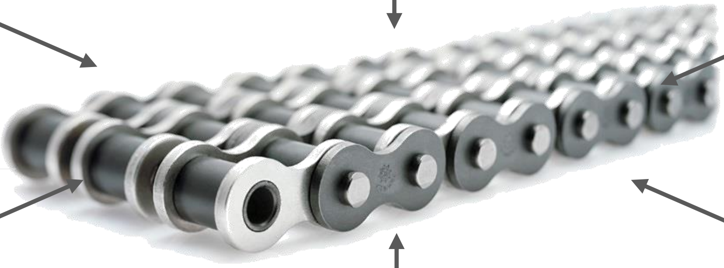
6) Lubrication, corrosion, coating, temperature

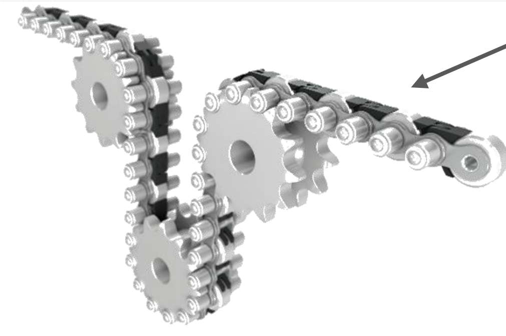
System approach

sprockets

environment

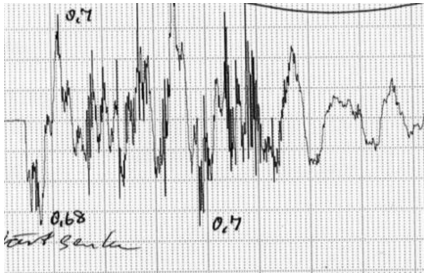
lubrication





arrangement

motion cycles



load spectrum

Service life: influence factors

chain drive design

chain type
- roller chain
- leaf chain
- etc.

size
- pitch
- Simplex / Duplex…

chain version
- standard
- stainless
- polymer bearings
- etc.

friction distance

distance of axles *a*

transmission ratio *i*

no. of teeth z_i

no. of sprockets and arrangement

application and environment

working load

preload

speed

temperature

application factors
- impact free
- medium impacts
- etc.

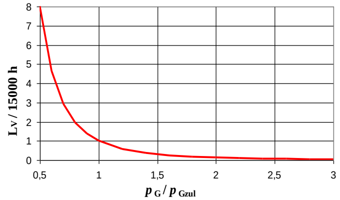
environment
- splash water
- under water
- etc.

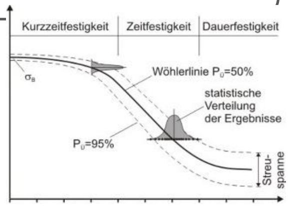
cleanliness
- dust free
- dirt
- etc.

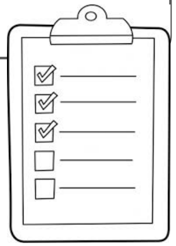
lubrication
- oil circulation
- manual
- none
- etc.

Calculation of service life depending on mechanism

	Wear	Breaking	Corrosion
procedure	Calculation of elongation due to wear in chain joints (frictional wear)	Calculation of (material-) fatigue of plates, pins, bushes calculation of breaking load	Selection under consideration of chemical resistance and compatibility
criterion	Max. allowable elongation (typisch 3%)	No. of load cycles for a given load until fatigue limit is reached, maximum breaking load	Corrosion tendency and admissible corrosion
model	Empirical, comparison of actual operation conditions to reference conditions, manufacturer know-how	Empirical test results, material model, simplified calculation models for chain parts	Specs, tables + experience







Influence factors on service life depending on mechanism

Wear

Actual joint pressure depending on:

- type (joint projection)
- loads

Admissible joint pressure depending on :

- type
- speed
- lubrication
- arrangement (length, sprockets etc.)
- elongation limit
- temperature
- environment

Break

- type
- load cycles
- breaking load
- endurance load
- temperature

Corrosion

- type (material)
- coating
- environment
- temperature
- lubrication

General design advices

- Transmission ratio:
  - normal speed: up to 4:1
  - slow speed : up to 7:1
- No. of teeth:
  - minimum no. of teeth: 11
  - slow speed: 11...17 (min.)
  - normal speed: 17...21 (min.)
  - high speed: 21... (min.)
  - maximum no. of teeth: 120
- Speed:
  - good up to 7 m/s
  - normal up to 12 m/s
  - possible up to 25 m/s
- Distance of axles:
  - 30...50 x chain pitch
- Slack:
  - slack side max. 1% of distance of axles

General design rules

- Selection guide:

Speed	Load	Pitch	No. strains
high	high	small	multi
high	medium	small	single
low	high	big	multi
low	medium	big	single

- Safety factor regarding breaking load
  - $S_{stat} = \frac{F_B}{F} \geq 7$
  - $S_{dyn} = \frac{F_B}{F_{dyn}} \geq 10$
- Contact pressure in roller-chain joints
  - $p = \frac{F}{f} \geq p_{Gzul}$
    - $p_{Gzul} = 5 \dots 45 \frac{N}{mm^2}$ for drive applications
    - $p_{Gzul} = 15 \frac{N}{mm^2}$ for lifting applications

Depending on:

- type
- pitch
- lubrication
- no. of links
- no. of teeth, deflections
- required service life
- version
- temperature
- speed
- environment
- application

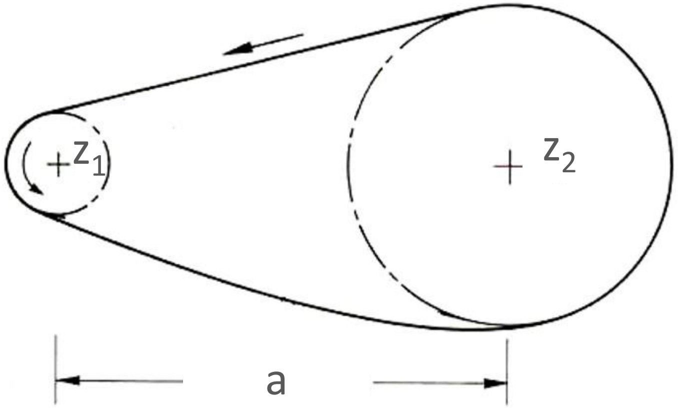
F_B Breaking load → see main catalogue

f Projection over joint → see main catalogue

Wear - service life: fundamentals of calculation

- Basis: empirical test data
- Calculation bases on a reference chain drive with an admissible load that depends on no. of teeth and speed
- Geometry

Designation	Symbol	Value
No. teeth (small sprocket)	z_1	19
Transmission ratio	i	3:1
Distance of axles	a	40p



  - good lubrication and cleanliness
  - uniform operation (without overload, impacts)
  - room temperature
  - etc…
- Reference service life is 15.000 hours

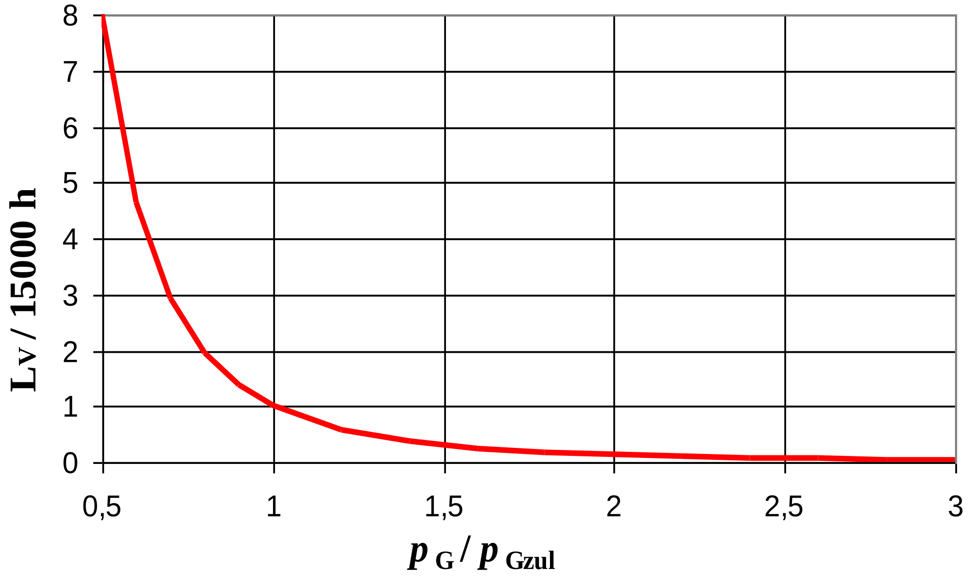
→ Actual operation conditions are considered through reduction or appreciation factors on admissible joint pressure

→ Precise application of factors are manufacturers know how

Wear - service life: basic formula

$$\boxed{L_\mathrm{V} = 15.000\ \mathrm{h} \cdot \left(\frac{\varepsilon_\mathrm{Aus}}{3\%}\right) \cdot \left(\frac{p_\mathrm{Gzul}}{p_\mathrm{G}}\right)^3}$$

L_V	wear service life in operation hours
admissible joint pressure	p_{Gzul}
actual joint pressure	p_G
operation limit in % elongation	ε_{Aus}



Wear - service life: joint pressure

$$\boxed{p_{\mathrm{G}} = \frac{F \cdot f_y}{f} \leq p_{\mathrm{Gzul}}}$$

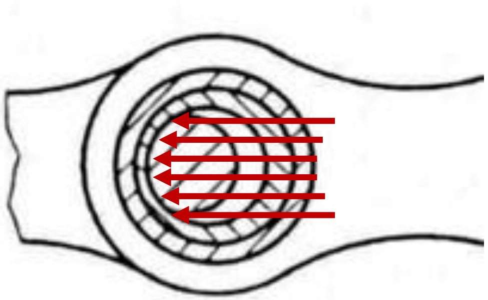
p_G actual joint pressure

tensile load F

operation coefficient (impact factor)) f_y

joint projection (see main catalogue) f

admissible joint pressure p_{Gzul}



Wear - service life: operation coefficient f_y

- Impacts and oscillations are taken into account by the operation coefficient f_y
- Thus the actual calculation load is increased with regard to the nominal value to take load peaks into account

Driven equipment Driving motor / engine	Centrifugal pumps and compressors Printing machines Conveyors with regular infeed Paper calenders Escalators Stirring devices for liquids Rotary driers Ventilators Generators (apart from welding generators)	Piston pumps and compressors with three or more cylinders Concrete mixers Conveyors with irregular feed Screw conveyors Rolling mills direct Saws and reciprocating saws Stirring devices for solid matter Spinning and rinsing machines Brick work machines	Planing machine and pulp grinders Excavators and other building plant Roller crushers Pulling machines Welding generators Choppers Rubber processing machines Piston pumps and compressors with one or two cylinders Gas or oil drill poles Driving motor / engine Dough mixers
Electric motors in continuous operation Internal combustion engines with hydraulic coupling Water, steam or gas turbines	1,0	1,4	1,8
Electric motors, which are repeatedly started and stopped with fewer than 10 cycles/min Internal combustion engines with six or more cylinders and mechanical coupling	1,1	1,5	1,9
Electric motors, which are repeatedly started and stopped with more than 10 cycles/min Internal combustion engines with fewer than six cylinders and mechanical coupling	1,3	1,7	2,1

Wear - service life: joint pressure

$$\boxed{p_{\mathrm{Gzul}} = p_{\mathrm{G0}} \cdot f_{\mathrm{R}} \cdot f_{\mathrm{S}} \cdot f_{\mathrm{K}} \cdot f_{\vartheta} \cdot f_{\mathrm{SA}}}$$

p_{Gzul} admissible joint pressure

admissible joint pressure under nominal operation conditions (see table)
→ takes into account: speed + no. of teeth p_{G0}

friction distance coefficient
→ takes into account: distance of axles + transmission ratio f_R

lubrication coefficient
→ takes into account: lubrication and operation conditions f_S

chain version coefficient
→ takes into account: type and version (e.g. standard, Marathon, stainless etc.) f_K

temperature coefficient
→ takes into account: operation temperatures f_ϑ

cleanliness coefficient
→ takes into account: cleanliness and environment f_{SA}

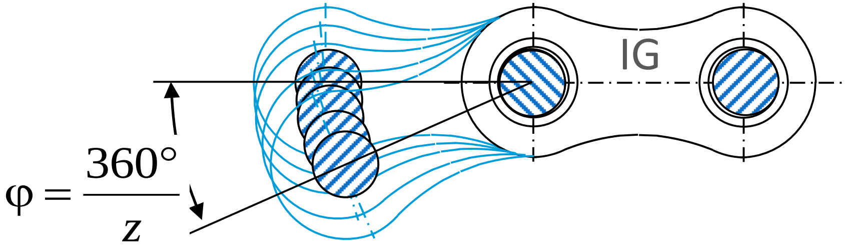
Admissible joint pressure under nominal operation conditions p_{G0}

Chain speed in m/s	Bearing pressure p_{G0} in N/cm2 with number of teeth z on smaller sprocket														
	11	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**≥25**
0,1	3080	3120	3170	3220	3270	3300	3320	3350	3400	3430	3450	3480	3500	3530	3550
0,2	2810	2850	2880	2930	2980	3000	3030	3060	3100	3120	3140	3170	3190	3220	3240
0,4	2700	2740	2780	2830	2870	2890	2910	2950	2980	3000	3020	3070	3070	3100	3120
0,6	2580	2620	2650	2700	2740	2760	2780	2820	2850	2870	2890	2910	2930	2960	2980
0,8	2490	2490	2560	2610	2650	2670	2680	2720	2750	2770	2790	2810	2830	2860	2880
1	2380	2420	2450	2490	2520	2540	2560	2590	2620	2640	2660	2680	2700	2720	2740
1,5	2290	2330	2360	2400	2430	2450	2470	2500	2530	2550	2570	2590	2610	2630	2650
2	2210	2240	2270	2310	2350	2370	2380	2410	2440	2460	2470	2490	2510	2530	2550
2,5	2130	2160	2190	2230	2260	2280	2290	2320	2350	2370	2380	2400	2440	2470	2500
3	2050	2080	2110	2140	2170	2190	2210	2240	2260	2290	2320	2350	2380	2420	2460
4	1740	1830	1920	2000	2070	2100	2130	2160	2180	2220	2260	2300	2340	2380	2420
5	1400	1550	1690	1770	1840	1910	1970	2010	2050	2100	2150	2180	2210	2240	2280
6	1050	1230	1410	1540	1640	1730	1810	1880	1950	1990	2040	2070	2110	2140	2180
7	850	1000	1150	1280	1400	1510	1620	1740	1850	1870	1900	1940	1980	2020	2060
8	-	800	1020	1110	1200	1310	1420	1560	1700	1740	1780	1820	1870	1910	1960
10	-	-	810	900	1020	1110	1200	1320	1430	1460	1500	1570	1640	1700	1770
12	-	-	-	-	820	910	1070	1170	1260	1300	1350	1410	1480	1540	1600
15	-	-	-	-	-	-	890	970	1050	1100	1150	1210	1270	1330	1400
18	-	-	-	-	-	-	-	-	880	960	1050	1110	1180	1240	1300

Wear - service life: friction distance coefficient f_R

- Friction distance coefficient f_R
  - Consideration of the actual swivel movement in chain joint compared to reference chain drive
  - Higher transmission ratios *i* result in bigger no. of teeth which result in smaller friction distance
  - Higher distance between axles result in less deviations per chain link

$$f_{\mathrm{R}} = \sqrt[3]{\frac{339 \cdot i}{L_{\mathrm{Vref}}} \cdot \left(\frac{a}{p} \cdot \frac{1}{i+1} + 4{,}75 \right)}$$

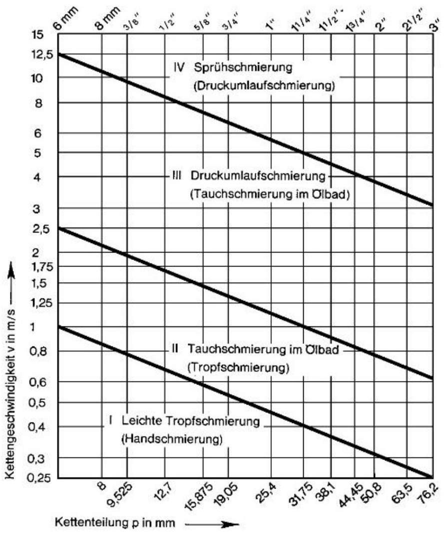


i	transmission ratio
a	distance of axles
p	pitch
L_{Vref}	reference service life (15.000 h)

Wear - service life: lubrication f_S

- Lubrication is most important to chain service life
- Lubrication reduces direct metal contact and prevents abrasive and adhesive wear
- Reduction of friction
- Required lubrication depends on operation conditions and chain type and version
- Rating by comparison of actual lubrication conditions and required lubrication (see chart)
- Special chains are rated differently than standard chains. E.g. a Marathon® chain needs no external lubrication and hence for no re-lubrication condition it is rated better than an unlubricated standard chain

lubrication recommendation (required lubrication)



f_S for standard chains

Soll\Ist	**Umlauf**	**Ölbad**	**Tropf-öler**	**manuell**	**keine**
Umlauf	1	0,6	0,1	0,1	0,01
Ölbad	1	1	0,6	[illegible]	0,05
Tropf-öler	1	1	[illegible]	0,4	0,1
manuell	1	1	1	1	0,3
keine	1	1	1	1	1

example values

Wear - service life: chain version f_K

- Every version shows a specific wear pattern
  - E.g. the hardness of stainless steel chain material is lower and hence SS chains are less wear resistant than standard chains
  - Chemical coated pins are more wear resistant than standard pins and hence Biathlon® chains have a higher version coefficient
- Wear resistance depends significantly on lubrication conditions
  - Under bad lubrication conditions a chain with sintered bush and oil reservoir (Marathon®) performs better than a standard chain → chain version has also impact on other coefficients (e.g. lubrication coefficient f_S)
  - This is also true for chains with polymer bearings (Triathlon®)

→Consideration of chain version coefficient is specific know how of chain manufacturer

f_K	**Version**
1,0	Standard
1,1	Biathlon
0,3..0,6	Stainless

example values

Wear - service life: temperature f_ϑ

- Temperature influences properties of chain parts and lubricant
- Low temperatures
  - embrittlement of steel parts → reduced load capacity
  - increased viscosity of lubricant „lubricant becomes sticky“
    → bad lubricant supply inside joint contact
- High temperatures
  - reduction of breaking stress of steel parts → reduced load capacity
  - reduced viscosity of lubricant „ lubricant becomes fluid“
    → good lubricant supply inside joint contact low load capacity of lubricant
    → at very high temperatures: evaporation of lubricant → dry run
- Effect of temperature depend on chain version
  - stainless steel is less influenced by temperature
  - polymer bearings can be designed for certain temperatures
  - high temperature lubricant is more tough and includes solid lubricant particles
  - etc…

standard chain

f_ϑ	temperature range	comment
0,5	-40 … -21 °C	bis 1 m/s
1,0	-20 … 149 °C	for correct lubrication
0,7	150 … 199 °C	for correct lubrication
0,4	199 … 280 °C	bis 1 m/s

Wear - service life: cleanliness f_{SA}

- Cleanliness f_{SA}
  - dirt absorbs lubricant
  - hard debris and particles can act like abrasive grits inside joint contacts and cause abrasive wear

f_{SA}	**cleanliness**
1	optimal
0,8	good
0,6	acceptable
0,2	bad

example values

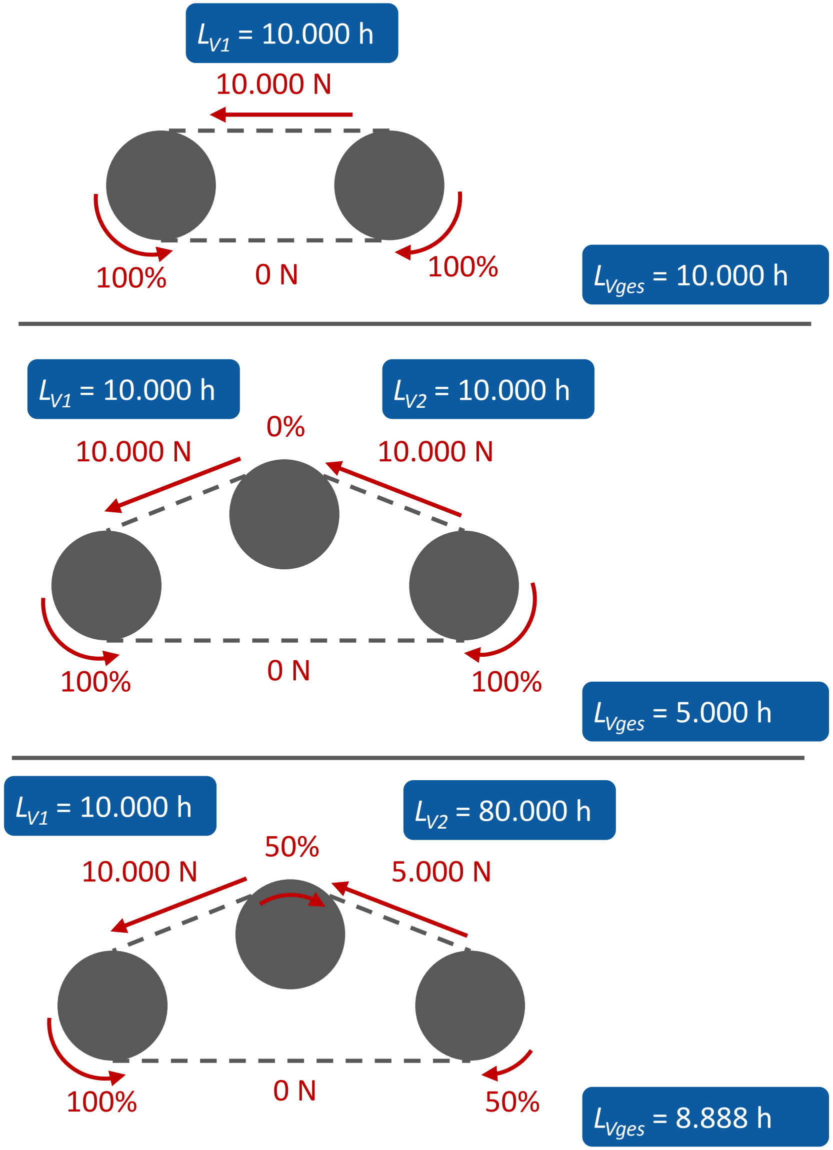
Example: influence of lubrication and cleanliness

Cleanliness	**f_{sa}**	**Lubrication**	**f_s**	**Service life**
optimal	1	optimal	1	15.000 h
good	0,8	manual instead of drip lubrication	0,4	491 h
bad	0,2	optimal	1	120 h

Wear - service life: number of shafts

- Additional sprockets / shafts result in a higher number of chain deflections per link → friction distance is increased
- Even small wrap angles cause a full in- and out swivel movement of the joint
- In case of different loads for between the sprockets for every section a service live is calculated separately
- The total service life $L_{V,ges}$ is determined as sum of service lives of all sections

$$L_{\mathrm{Vges}} = \left(\frac{1}{L_{\mathrm{V1}}} + \frac{1}{L_{\mathrm{V2}}} + \frac{1}{L_{\mathrm{V3}}} + \dots \right)^{-1}$$

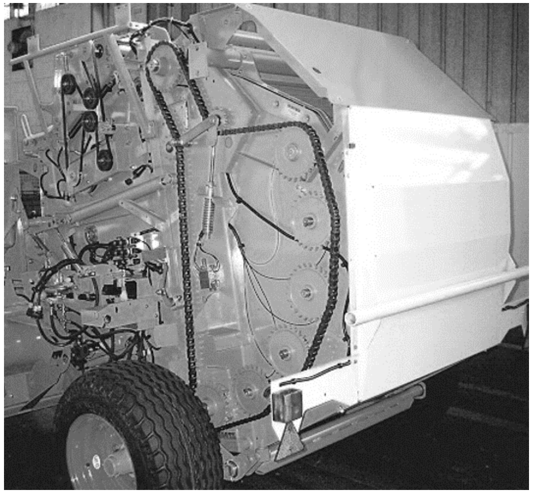


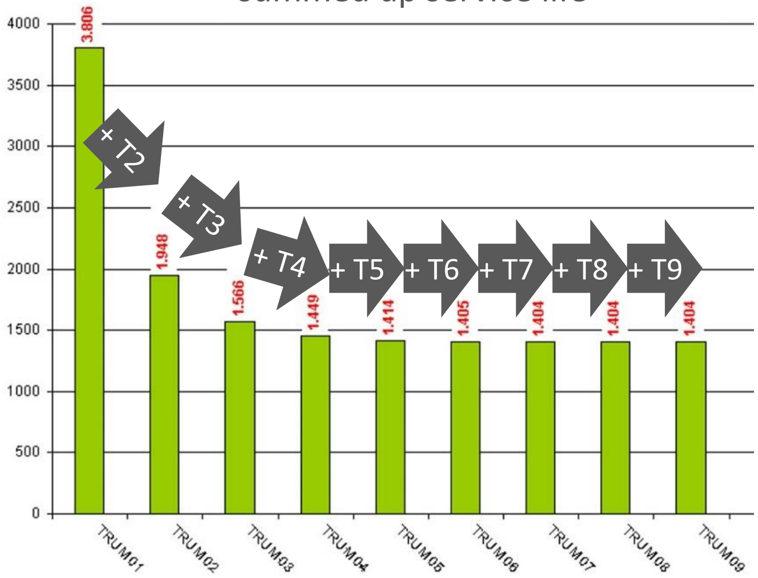
L_{V1} = 10.000 h
10.000 N
100%
0 N
100%
L_{Vges} = 10.000 h

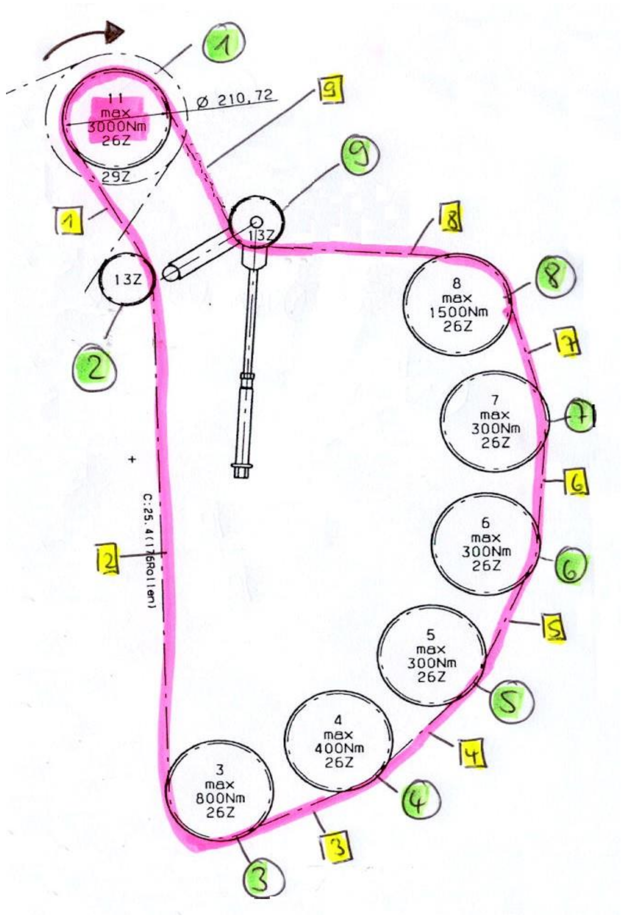
L_{V1} = 10.000 h
L_{V2} = 10.000 h
0%
10.000 N
10.000 N
100%
0 N
100%
L_{Vges} = 5.000 h

L_{V1} = 10.000 h
L_{V2} = 80.000 h
50%
10.000 N
5.000 N
100%
0 N
50%
L_{Vges} = 8.888 h

Example: calculation of a baler drive




summed up service life

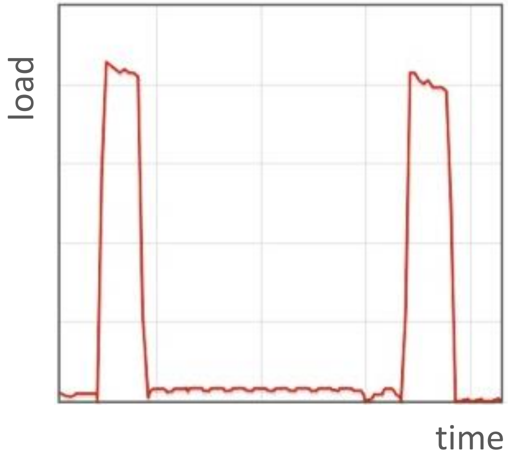


12 sprockets with different torques

→ Software

Wear - service life: cycles

- If loads varies over time with a know cycle, e.g. by means of different operation modes
  - processing / idle
  - load lifting / idle
  - positioning / set up / rapid traverse / cleaning
  - etc…
- The service life values for every operation mode are summed up considering its proportion of time

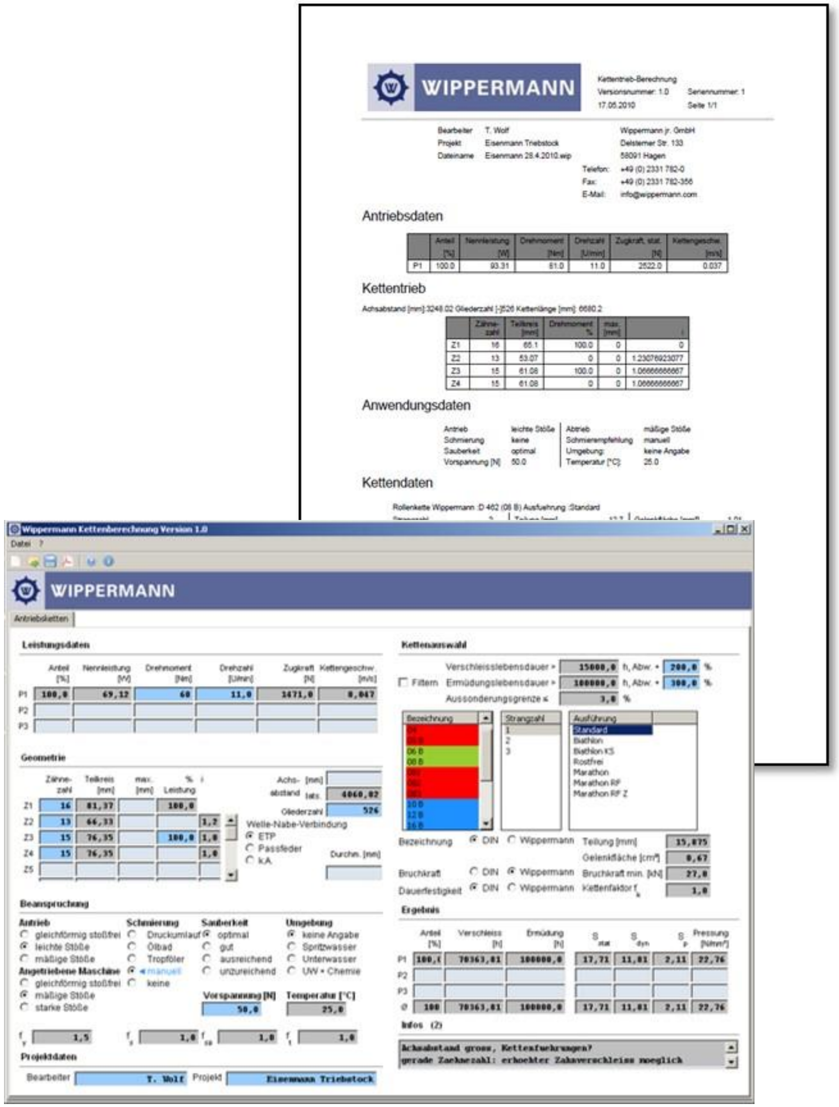


$$L_{\mathrm{Vges}} = \left(\frac{1}{L_{\mathrm{V1}}} \cdot \frac{\Delta t_1}{t_{ges}} + \frac{1}{L_{\mathrm{V2}}} \cdot \frac{\Delta t_2}{t_{ges}} + \frac{1}{L_{\mathrm{V3}}} \cdot \frac{\Delta t_3}{t_{ges}} + \dots \right)^{-1}$$

Fatigue life

- In practice fatigue of plates induced by alternating loads are the main cause of fatigue failures
- Calculation can be done with approximation formulas
- Influence factors
    - dynamic load (load rated with operation coefficient)
    - number of teeth
    - pitch

Calculation software WIPPlife



Kettentrieb-Berechnung
Versionsnummer: 1.0 Seriennummer: 1
17.06.2010 Seite 1/1

Bearbeiter T. Wolf
Projekt Eisenmann Triebstock
Dateiname Eisenmann 28.4.2010.wip

Wippermann jr. GmbH
Delsterner Str. 133
58091 Hagen
Telefon: +49 (0) 2331 782-0
Fax: +49 (0) 2331 782-356
E-Mail: info@wippermann.com

Antriebsdaten

	Anteil [%]	Nennleistung [W]	Drehmoment [Nm]	Drehzahl [U/min]	Zugkraft, stat. [N]	Kettengeschw. [m/s]
P1	100.0	93.31	81.0	11.0	2522.0	0.037

Kettentrieb

Achsabstand [mm]:3248.02 Gliederzahl [-]:526 Kettenlänge [mm]: 6680.2

	Zähne-zahl	Teilkreis [mm]	Drehmoment %	max. [mm]	i
Z1	16	65.1	100.0	0	0
Z2	13	53.07	0	0	1.23076923077
Z3	15	61.08	100.0	0	1.06666666667
Z4	15	61.08	0	0	1.06666666667

Anwendungsdaten

Antrieb	leichte Stöße	Abtrieb	mäßige Stöße
Schmierung	keine	Schmierempfehlung	manuell
Sauberkeit	optimal	Umgebung:	keine Angabe
Vorspannung [N]	50.0	Temperatur [°C]:	25.0

Kettendaten

Rollenkette Wippermann :D 462 (08 B) Ausfuehrung :Standard

Wippermann Kettenberechnung Version 1.0

Datei ?

WIPPERMANN

Antriebsketten

Leistungsdaten

	Anteil [%]	Nennleistung [W]	Drehmoment [Nm]	Drehzahl [U/min]	Zugkraft [N]	Kettengeschw. [m/s]
P1	100,0	69,12	60	11,0	1471,0	0,047
P2						
P3						

Geometrie

	Zähne-zahl	Teilkreis [mm]	max. [mm]	% Leistung	i
Z1	16	81,37		100,0	
Z2	13	66,33			1,2
Z3	15	76,35		100,0	1,0
Z4	15	76,35			1,0
Z5					

Achs-abstand [mm]
Achs-abstand Ist: 4060,02
Gliederzahl: 526

Welle-Nabe-Verbindung
● ETP
○ Passfeder
○ k.A.
Durchm. [mm]

Beanspruchung

Antrieb
○ gleichförmig stoßfrei
● leichte Stöße
○ mäßige Stöße

Angetriebene Maschine
○ gleichförmig stoßfrei
● mäßige Stöße
○ starke Stöße

Schmierung
○ Druckumlauf
○ Ölbad
○ Tropföler
● ◄manuell
○ keine

Sauberkeit
● optimal
○ gut
○ ausreichend
○ unzureichend

Umgebung
● keine Angabe
○ Spritzwasser
○ Unterwasser
○ UW • Chemie

Vorspannung [N] 50,0
Temperatur [°C] 25,0

f_y 1,5 f_s 1,0 f_{sa} 1,0 f_t 1,0

Projektdaten

Bearbeiter: T. Wolf Projekt: Eisenmann Triebstock

Kettenauswahl

☐ Filtern

Verschleisslebensdauer > 15000,0 h, Abw. < 200,0 %
Ermüdungslebensdauer > 100000,0 h, Abw. < 300,0 %
Aussonderungsgrenze ≤ 3,0 %

Bezeichnung	Strangzahl	Ausführung
06 B 08 B 10 B 12 B 16 B	1 2 3	Standard Biathlon Biathlon KS Rostfrei Marathon Marathon RF Marathon RF Z

Bezeichnung ● DIN ○ Wippermann
Bruchkraft ○ DIN ● Wippermann
Dauerfestigkeit ● DIN ○ Wippermann

Teilung [mm] 15,875
Gelenkfläche [cm²] 0,67
Bruchkraft min. [kN] 27,0
Kettenfaktor f_k 1,0

Ergebnis

	Anteil [%]	Verschleiss [h]	Ermüdung [h]	S_{stat}	S_{dyn}	S_p	Pressung [N/mm²]
P1	100,(	70363,01	100000,0	17,71	11,01	2,11	22,76
P2							
P3							
Ø	100	70363,01	100000,0	17,71	11,01	2,11	22,76

Infos (2)

Achsabstand gross, Kettenfuehrungen?
gerade Zaehnezahl: erhoehter Zahnverschleiss moeglich

- Geometric design and calculation of wear life
  - distance of axles
  - sprocket geometry
- Considering:
  - preload
  - several sprockets
  - lubrication, environment and operation coefficient
  - chain versions (standard, Biathlon, Marathon, Triathlon, RF etc.)
  - temperature
- Integrated Wippermann chain database
- Filter- and suggestion functions
- Direct pdf-export
- Additional information

Agenda

- 1) Structure, terms and classification as machine element
- 2) Forces, torques, kinematics
- 3) Arrangement and mounting
- 4) Tribology, wear and failure mechanisms
- 5) Design and calculation
- 6) Lubrication, corrosion, coating, temperature

Function of lubricant

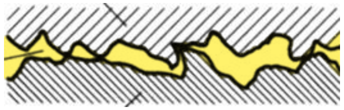
- Separation of contact partners
  - pin - bush
  - roller - bush

  →reduction of friction

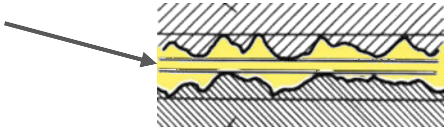
    → efficiency

    → loads

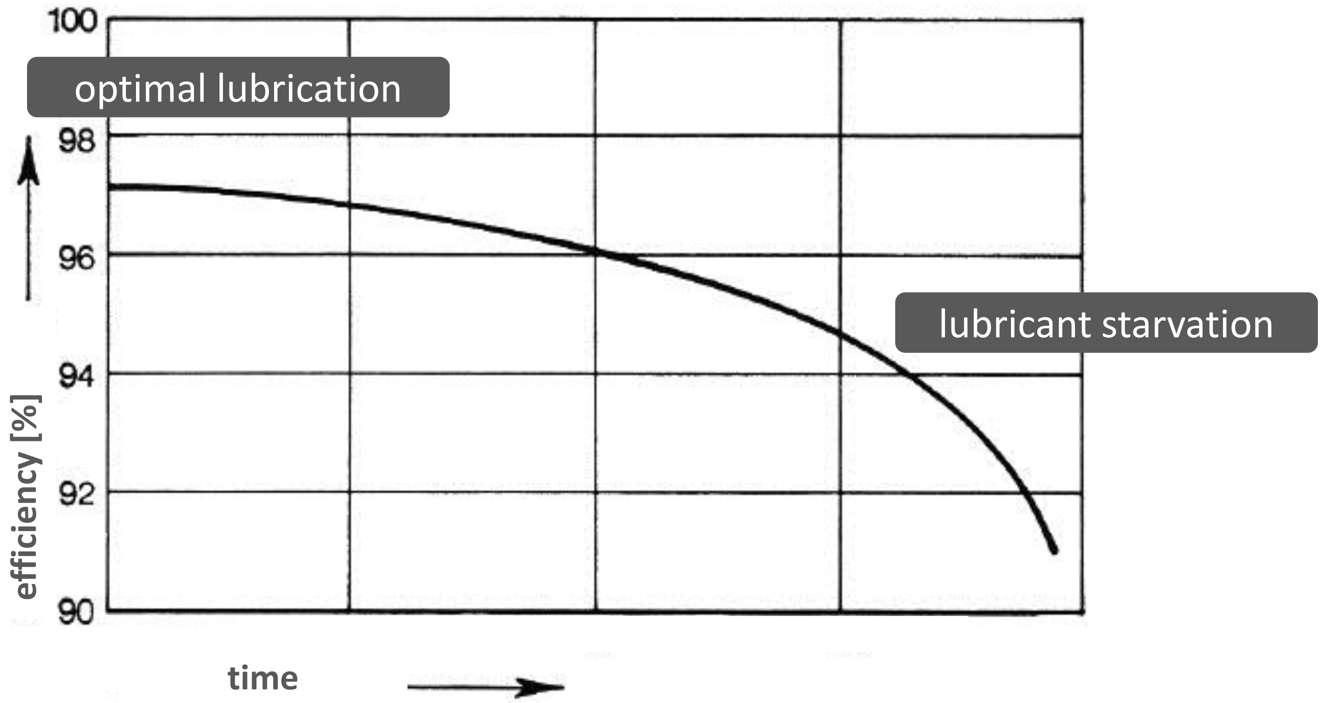
  →reduction of wear
- Corrosion protection



objective: bearing lubricant film



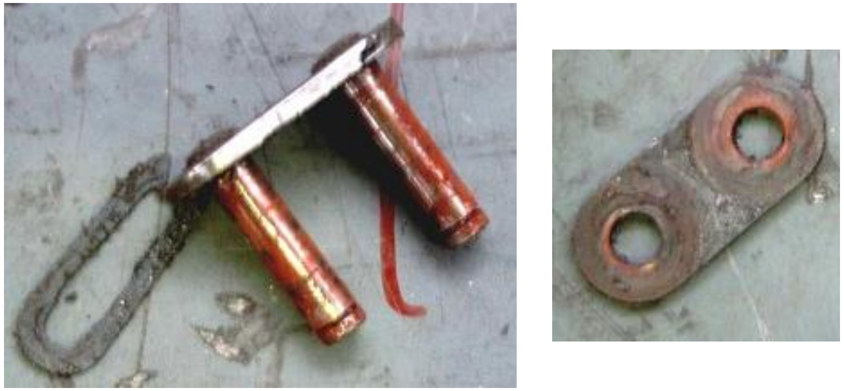
Efficiency depending on lubrication condition



power loss:

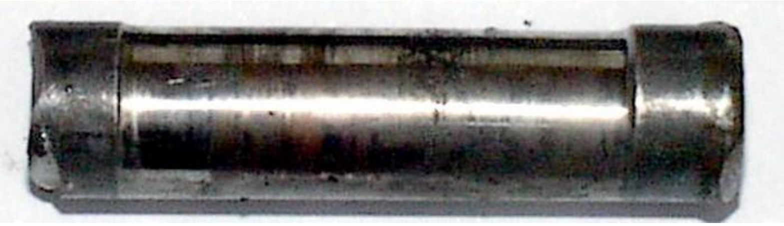
- friction (heat)
- wear
- vibrations / oscillations
- noise

Results of bad lubrication

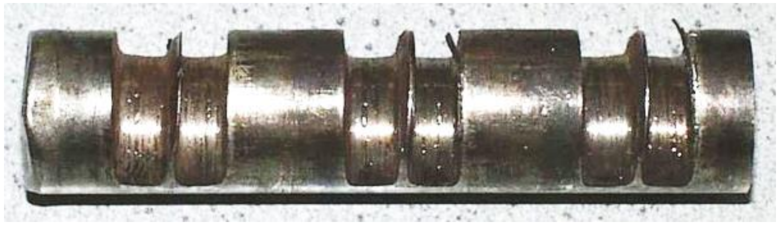


friction rust caused by dry run

tilted pin caused by high friction forces

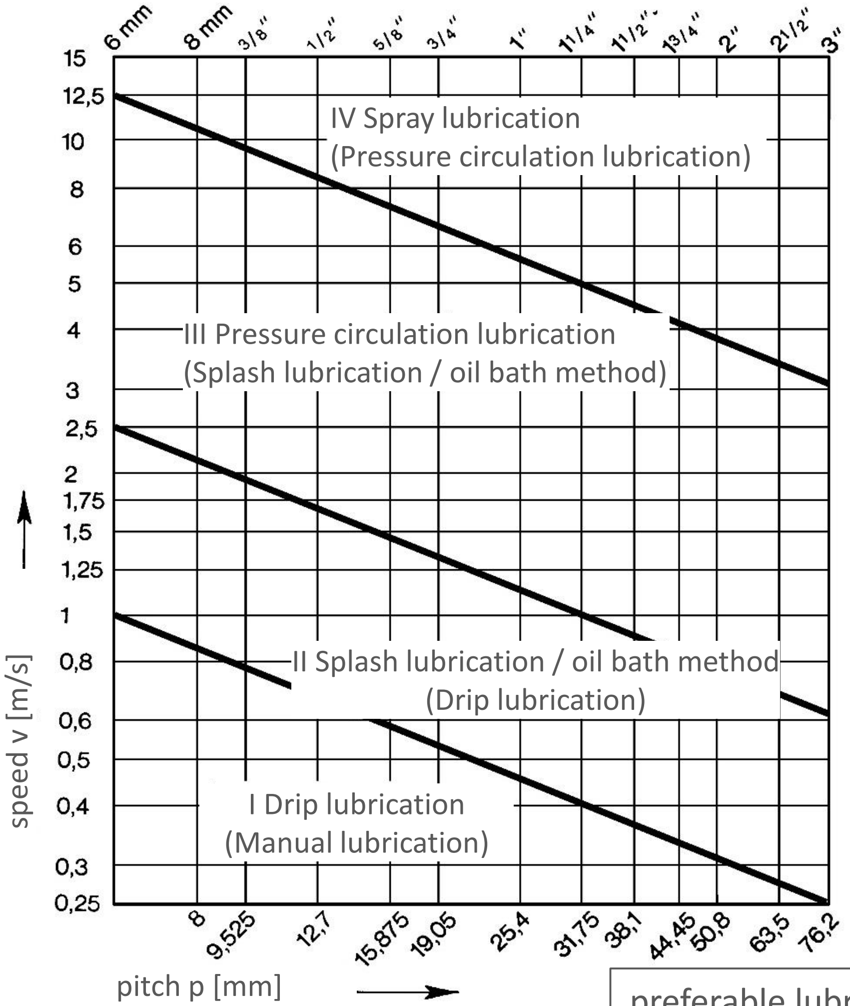


heavy wear on a roller chain pin



heavy wear on a leaf chain pin

Lubrication regimes

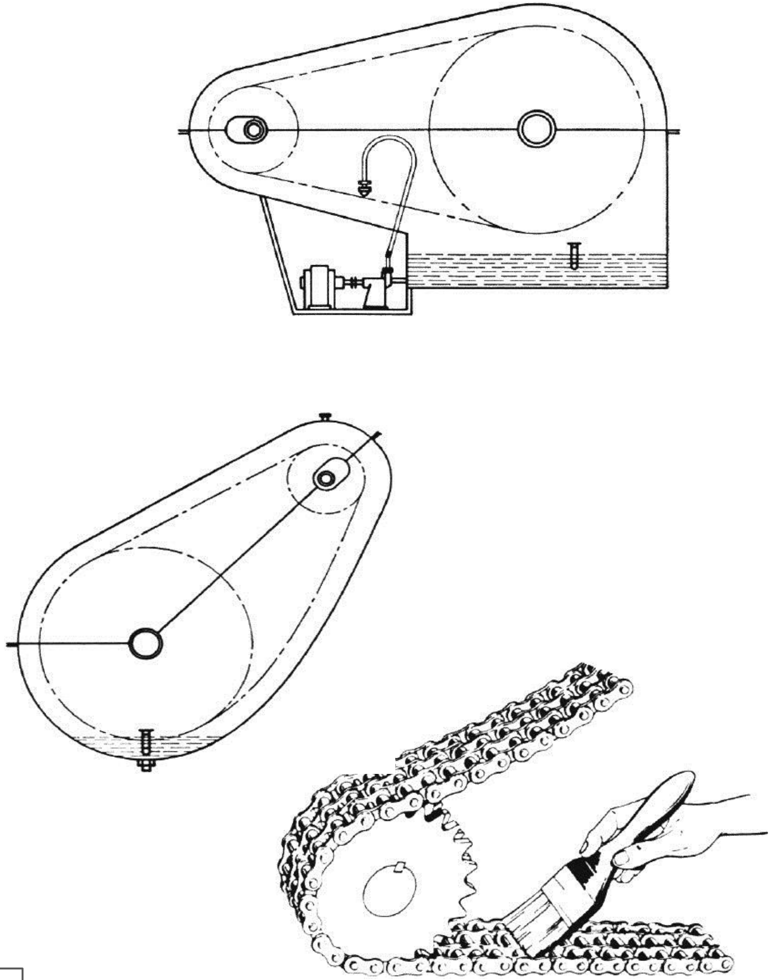


IV Spray lubrication
(Pressure circulation lubrication)

III Pressure circulation lubrication
(Splash lubrication / oil bath method)

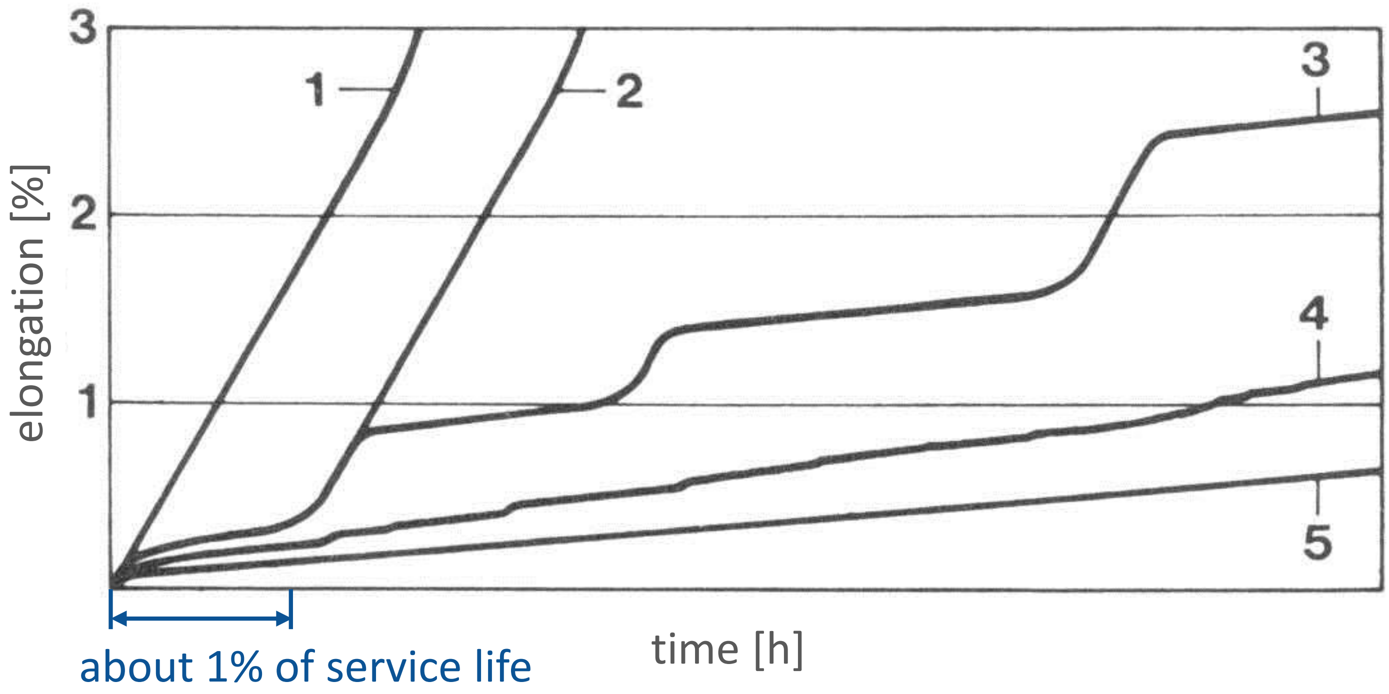
II Splash lubrication / oil bath method
(Drip lubrication)

I Drip lubrication
(Manual lubrication)

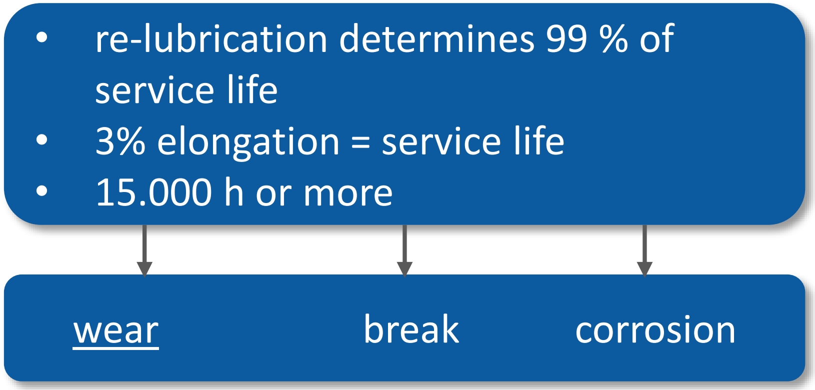


preferable lubrication
(permitted lubrication)

Chain elongation depending on lubrication



1) no lubrication
2) initial lubrication, no re-lubrication
3) re-lubrication, interval to long (dry run at times)
4) re-lubrication, wrong or contamined lubricant
5) optimum lubrication



- re-lubrication determines 99 % of service life
- 3% elongation = service life
- 15.000 h or more

wear break corrosion

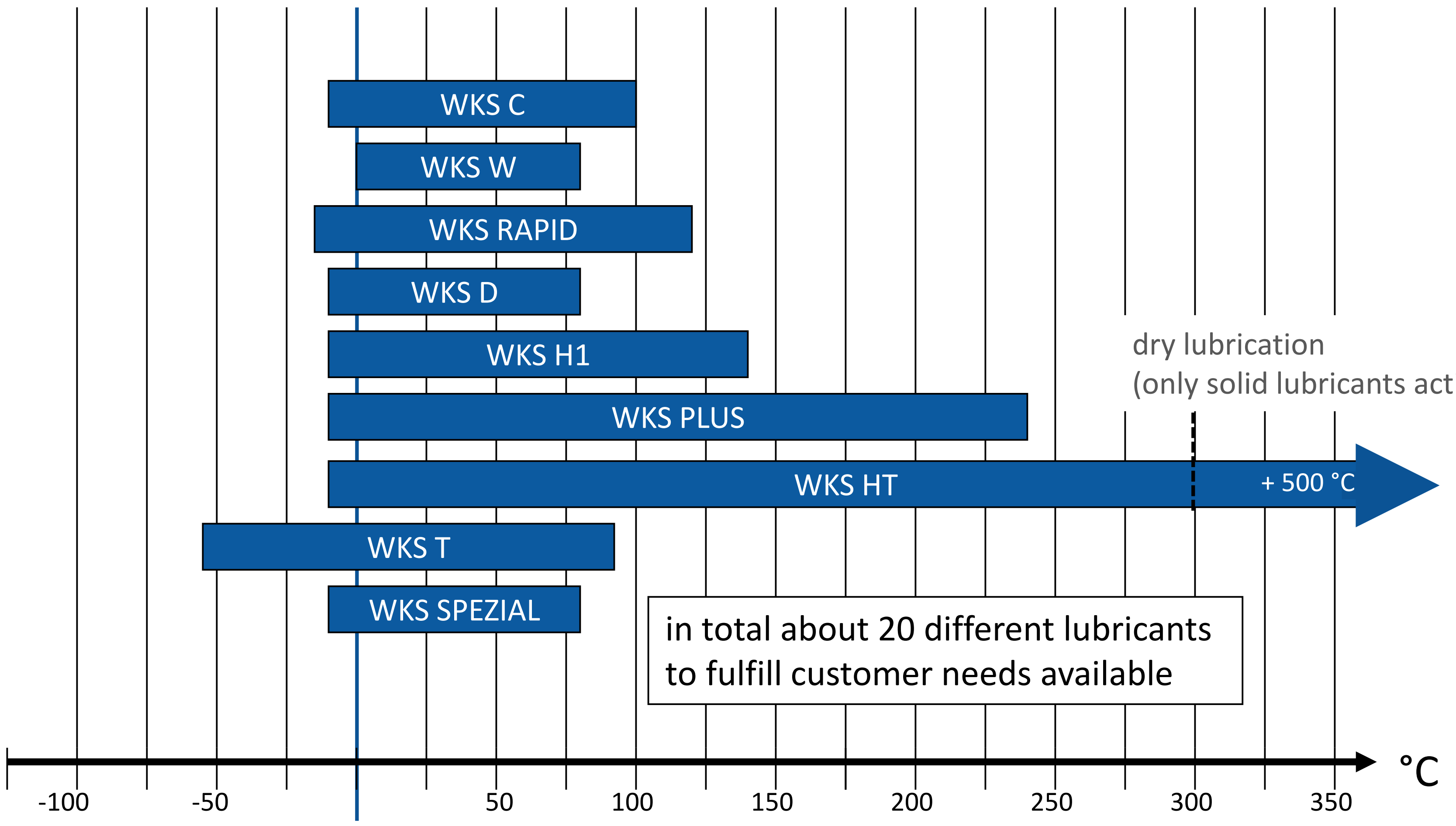
Lubricant properties

- Lubricant should be fluid so that it can easily flow into contact zone
  → low viscosity
- Lubricant should build a bearing lubrication film in contact and stick to the chain → high viscosity
- Informations regarding temperature ranges of lubricants refer mainly to its thermal stability. If lubricant properties are still adequate for the chain application has to be evaluated separately
- The open tribological system “Chain” causes a loss of lubricant at higher temperatures. This is normal and no defect of the lubricant.
- If a loss of lubricant (dripping) can not be accepted in the application this has to be indicated. In this case a lubricant free solution should be used (e.g. Triathlon® chains)

WKS-lubricants for initial lubrication

Application	WKS-Product	Temperature	Properties
demanding applications	WKS-C	-10...100 °C	grease: high additives, Wippermann standard lubrication
grip dry	WKS-W	0...80 °C	grease: high wax portion, non-tacky
difficult conditions	WKS-Rapid	-15...120 °C	grease: difficult to centrifuge of, protects against corrosion and wear, water resistant
corrosion protection	WKS-D	-10...80 °C	oil: mineral oil with corrosion protection additives, thin
food industry	WKS-H1	-10...140 °C	oil: NSF-H1 listed
high temperatures automotive industry	WKS-Plus	-10...240 °C	oil: spray: synthetic ester oil, lacquer compatibility
extreme temperatures	WKS-HT	-10...500 °C	oil: with solid lubricants (graphite), from 300°C dry lubrication
low temperatures	WKS-T	-55...90 °C	oil: synthetic ester oil with low viscosity
spray for re-lubrication	WKS-Special	-10...80 °C	spray: mineral oil with special additives

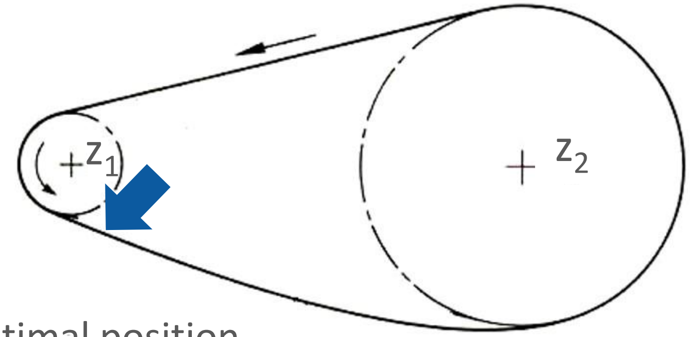
Temperature range of lubricants



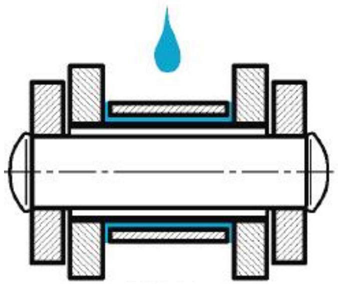
in total about 20 different lubricants to fulfill customer needs available

Instruction for chain lubrication - application

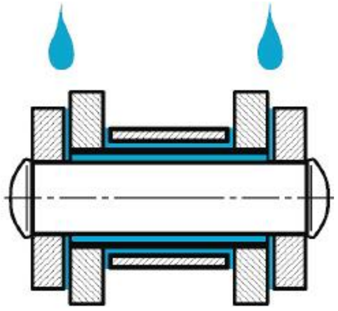
- Re-lubrication should be applied in the unloaded section of the chain (slack side) to enable lubricant flow into contact zone
  → optimum: **inner side of slack side at point of discharge of drive sprocket**
- Lubricant has to be applied in the gap between inner and outer links
- Do not smear the chain external with sticky lubricant. This can result in "sealed" joints and hence impossible re-lubrication and deposition on dirt particles
- Lubricate in moderate amounts, this means the lubricant should not be dripping off the chain in higher amounts



optimal position



wrong



right

Instruction for chain lubrication

- Cleaning of dirty chains
  - Only use paraffin derivatives (diesel, paraffin, benzine)
  - Optional with a brush
  - Do not use steam
- Choice of lubricant
  - Use a suitable, low viscosity lubricant (see below)
  - Use WKS lubricants for re-lubrication or low viscosity mineral- machine or synthetic oils
  - Lubricant properties should ensure that external dirt does not stick to the chain and that corrosion is prevented
  - Suitable viscosity grades depending on temperature:
    - -5...25°C ISO VG 100
    - 25...45°C ISO VG 150
    - 45...65°C ISO VG 220

Responsibility for lubrication over lifetime

Who?	**Function**
chain manufacturer	initial lubrication corrosion protection recommendation for re-lubrication
machine and plant manufacturer	access for manual re-lubrication chain boxes oil bath lubrication system re-lubrication schedules, -amounts and -products
machine and plant operator	check of lubrication carry out re-lubrication schedules of necessary: correction of schedules, amounts cleaning chain preservation new lubrication

Corrosion- and wear protection

Corrosion protection

Wear protection

stainless steel products

- material 1.4301
- material 1.4310
- optional: special materials

functional coatings

- lubricant with corrosion protection
- galvanically nickel-plated
- galvanized, yellow chromated
- chemically nickel-plated
- Zn-Al-flake-coated
- ...

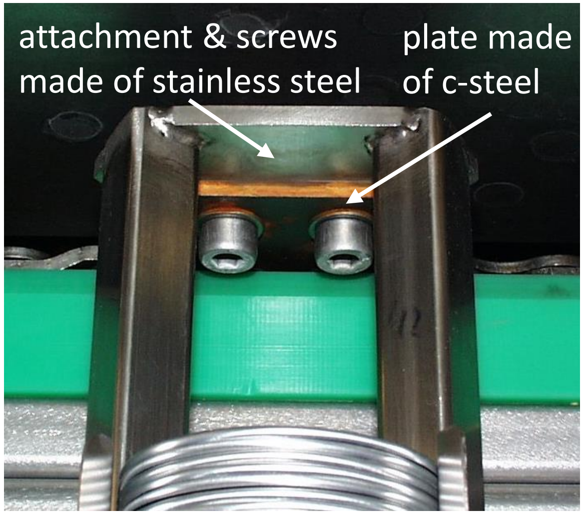
Stainless steels

Typ	Material no.	Description	Resistance			
			against rust	against acid	strength	weldability
A1	1.4300; 1.4305; 1.4310	good processing	medium	low	low; class 50	poor
A2	1.4301; 1.4306	= classic stainless steel	high	low	medium; class 70	good
A3	1.4550; 1.4590		high	medium	medium; class 70	good
A4	1.4401; 1.4404	= stainless steel for high acid applications	high	high	medium; class 70; class 80 possible	good
A5	1.4436; 1.4571; 1.4580	= stainless steel with special strength	high	high	high	good

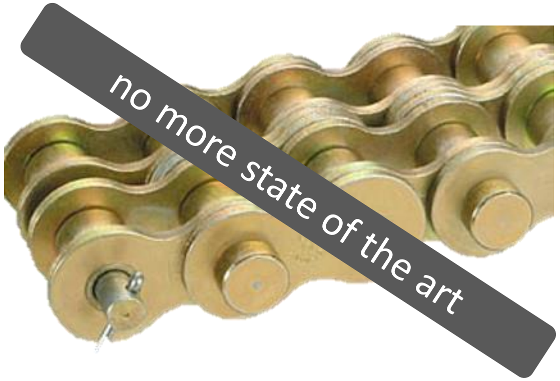
Chemical composition (analysis [%])

C	Si	Mn	P	S	Cr	Ni
< 0,07	< 1,0	< 2,0	< 0,045	< 0,03	17,0 - 19,5	8,0 - 10,5

Consider chemical compatibility of attachment parts and supporting components.
Especially Cr and Ni portions have to be similar to prevent electro chemical contact corrosion.



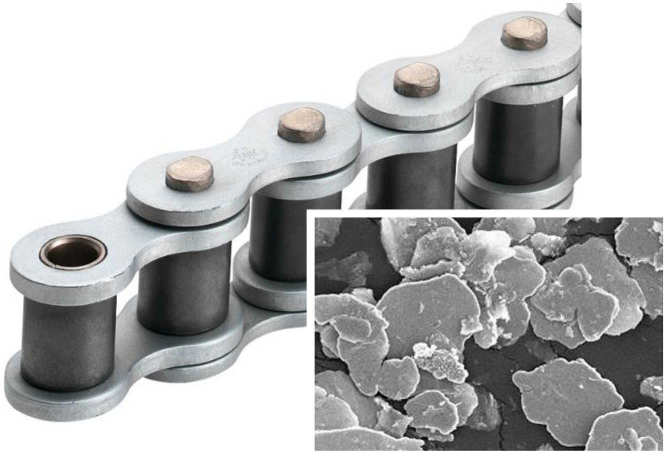
Roller chains with corrosion protection coatings



no more state of the art

galvanized, (yellow chromated)
containing CrVI

galvanically nickel-plated



Zn-Al-flake-coated

chemically nickel-plated

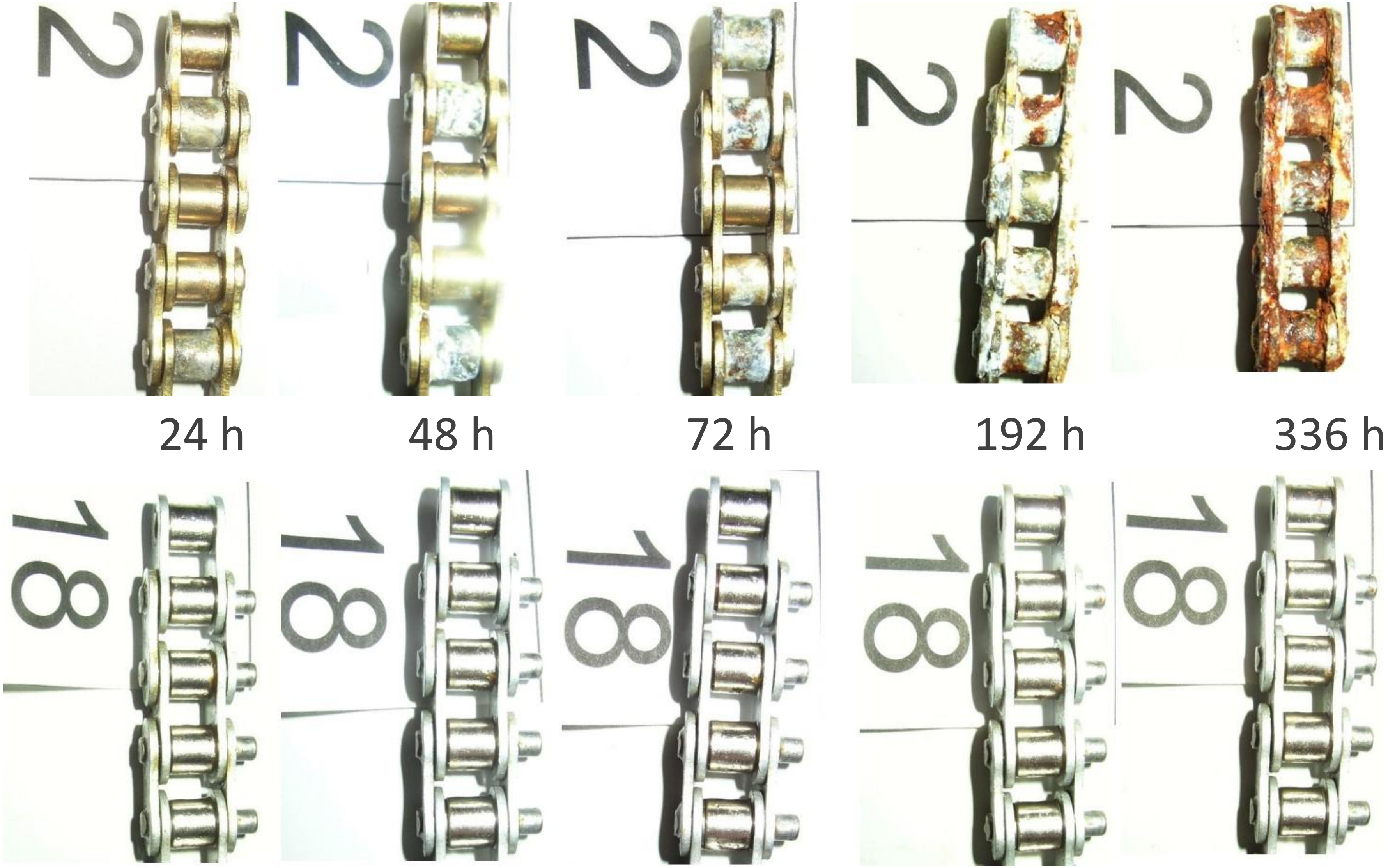
Comparison of corrosion protection coatings

Coating	Cost	Resistance DIN 50021 SS	Resistance experience	Comment
galvanized, (yellow chromated)*	+++	50 ... 100 h	+	red rust after about 100 h
galvanically nickel plating	++	ca. 25 h	+ ... ++	better with lubricant
chemically nickel plating	o	resistent	++++	erosion in µm range
Zn-Al-flake	+	> 480 h ... resistent	+++	cathodic remote protection

*Cr(VI)

standard chain, lubricated, after salt spray test DIN 50021 SS

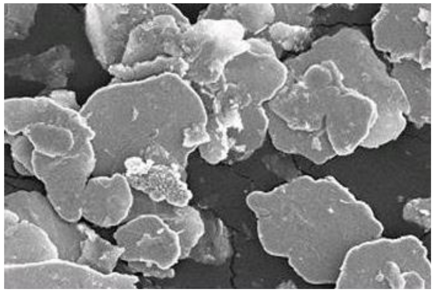
Example: results salt spray test according to DIN EN ISO 9227



Zn-Al-flake coatings - function

Base layer

- 80% of weight Zn- and Al-flakes
- cross-linking at 180-210 °C
- cathodic remote protection
- Cr(VI) free, no heavy metals (e.g. cadmium)
- drinking water approval
- temperature stable > 150°C
- uniform layer thickness
- good ductility
- no hydrogen embrittlement



Top layer

- good chemical resistance
- ductile, good adhesive strength, free of porosities
- with slip additives, low and constant friction coefficient
- delay of contact corrosion
- electrically insulating

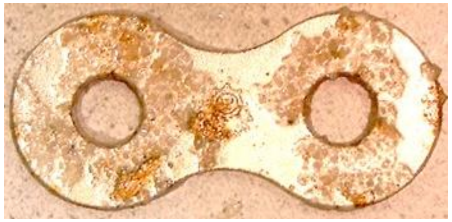
- significant better corrosion protection compared to galvanically nickel-plated
- salt spray test DIN 510021 SS > 500 h
- coating thickness total about 15µm

Test results: different corrosion protection coatings

- Zn-Al-Flake coated inner and outer plate
- after 4 weeks in concentrated saline solution
  → little corrosion

- galvanized, (yellow chromated) outer plates
- 12 hours in concentrated saline solution

→ corrosion visible



- galvanically nickel-plated outer plates
- 12 hours in concentrated saline solution

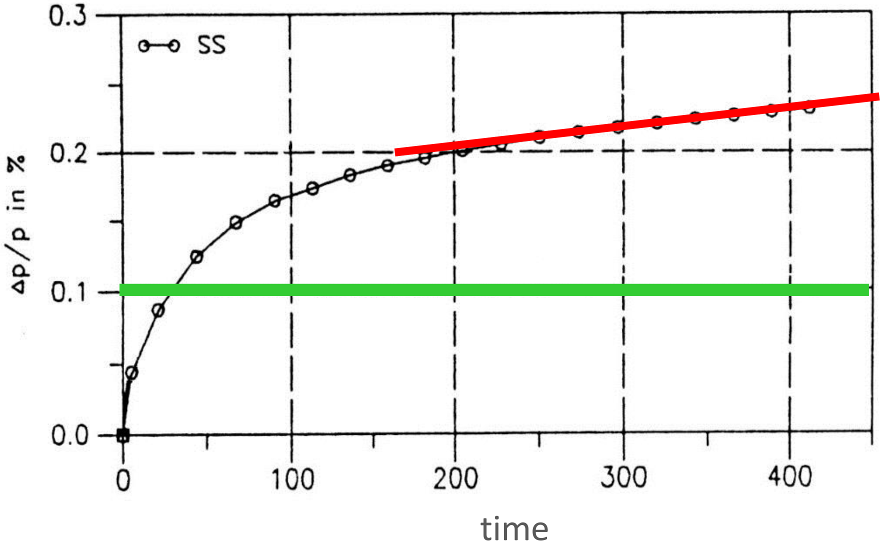
→ heavy corrosion visible

Properties of chemically nickel plating

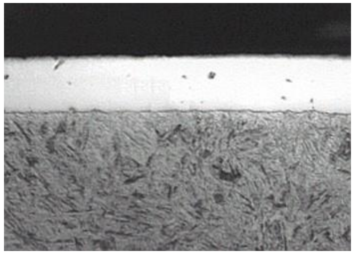
characteristic	effect
high hardness	high resistance against abrasive wear through hard particles
phosphorus proportion	high resistance against abrasive wear = good fail-safe properties through reaction layers
nickel proportion	corrosion protection an protection against tribooxidation

Wear resistance of chemically nickel plating

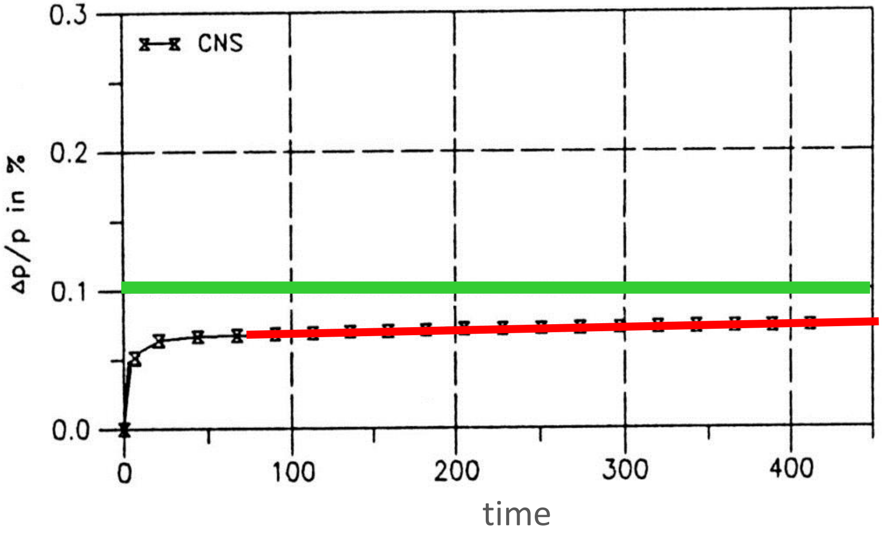
pin:	case hardening steel
bush:	case hardening steel



pin:	chem. nickel-plated
bush:	case hardening steel

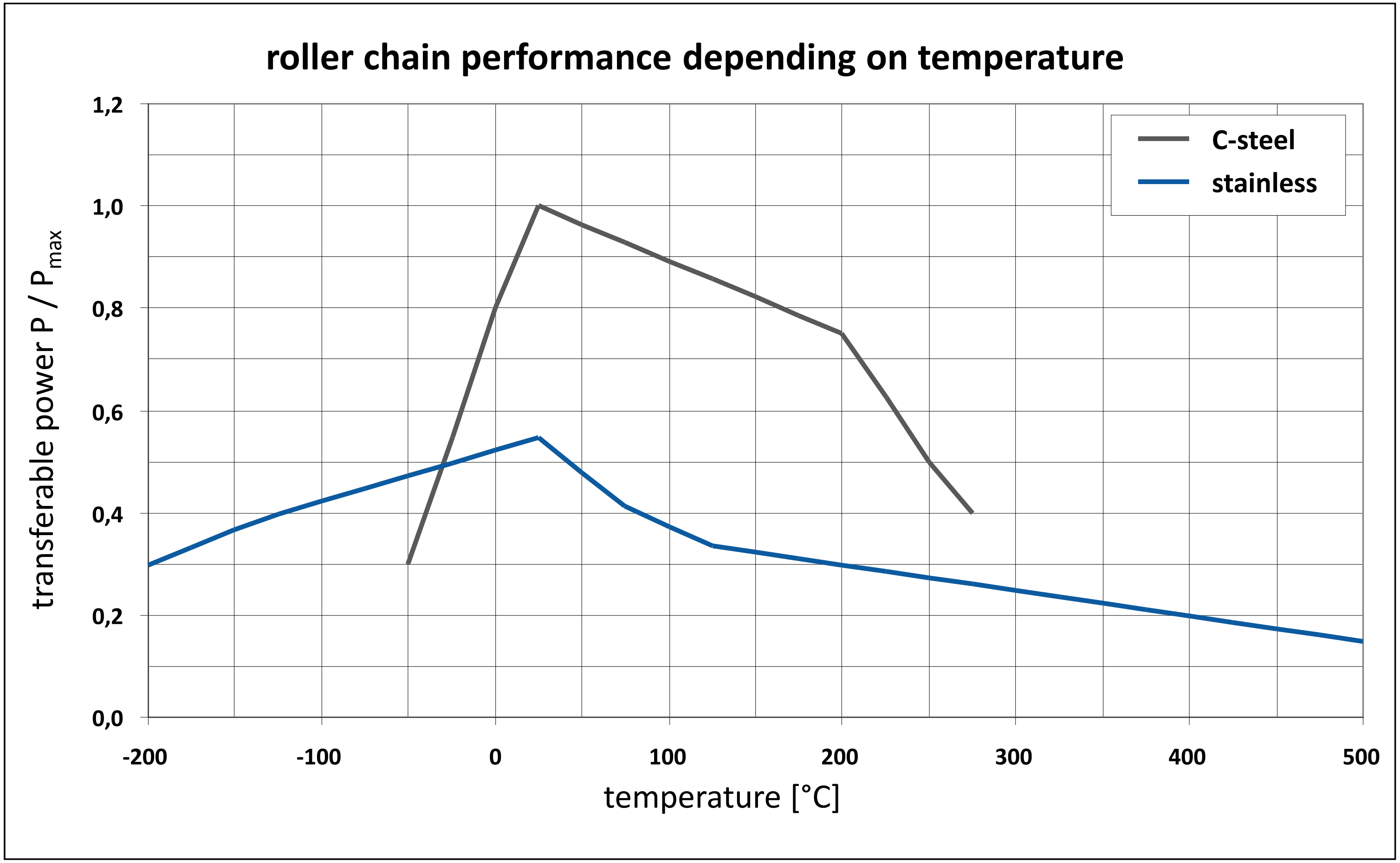


→ formation of a low friction reaction layer by phosphorus



Quelle: Diss. A. Pawlik

Influence of temperature on steel material



Temperature compensation of chain breaking load

Material	Temperature	Compensation coefficient for chain breaking load*
C-steel (standard)	- 40 ...- 21 °C	0,5 · F_B
	- 20 ...+ 150 °C	1,0 · F_B
	+ 151 ...+ 200 °C	0,7 · F_B
	+ 201 ...+ 280 °C	0,4 · F_B
Stainless steel (austenite)	- 196 ...– 41 °C	0,7 · F_B
	- 40 ...+ 100 °C	1,0 · F_B
	- 101 ...+ 200 °C	0,8 · F_B
	+ 201 ...+ 300 °C	0,75 · F_B
	+ 301 ...+ 400 °C	0,7 · F_B

* values for F_B: see main catalogue

Chain application temperatures