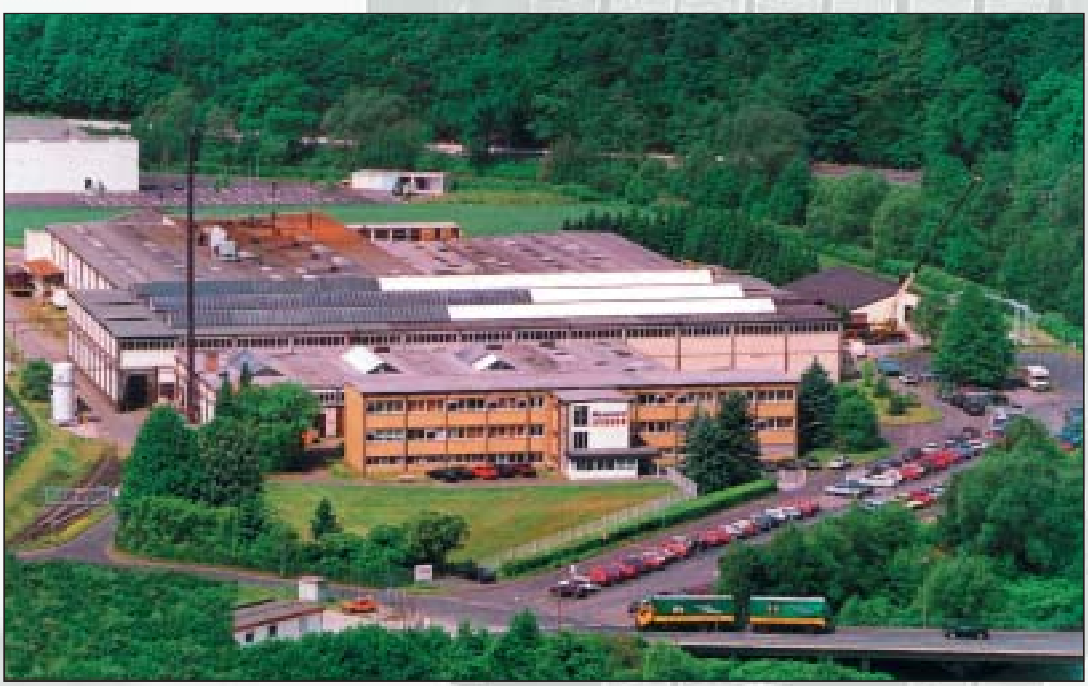
Rexnord

. . . MOVING AHEAD

Leaf Chain Technology

A guide to the realistic consideration and design of the leaf chain as a safety element



Betzdorf/Sieg
General Headquarters
and factory.

Preface

The task of this technical treatise on leaf chains is to explain relationships and influencing factors which determine the function and the quality of leaf chains in a comprehensible form.

Furthermore, the fields of use and the appropriate design of the leaf chain as a safety element is presented and realistically examined with the help of examples.

A chapter on maintenance and lubrication gives you practicable tips on the servicing of your leaf chains.

Moreover, we would like to start a dialogue with you when you come across borderline cases in chain design or if your special application makes extraordinary demands on the leaf chain.

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We reserve the right to change the construction of our products subject to modifications to the construction of our products, errors accepted.

Contents: Department of development and technical consulting, Rexnord Kette, Betzdorf

Design: Advertising department Rexnord Kette, Betzdorf

Think like partners – act like partners

Speed

The speed with which modern technologies change our world is breathtaking.

For us two aims are certain:

We are determined, with our products for our customers, to occupy a leading position as regards technology.

We want, together with our customers, to achieve quality and sales growth.

Consulting

Our application engineers concentrate on the customer's interests.

We concentrate on the individual wishes and needs of the customer when calculating and identifying the correct chain drive.

Together with our customers, we find solutions, which optimize the factors of safety, service life and price.

Partnership

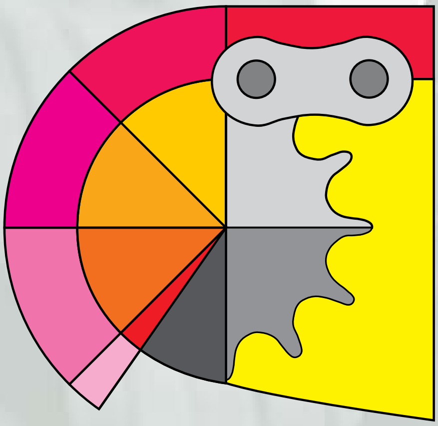
We know what the customer needs in his market for his product in the future.

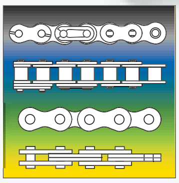
We listen to you and observe driving and conveying world-wide. We carry out analyses on the customer's premises and apply practicable solutions. So that you remain competitive.

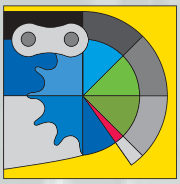
Service

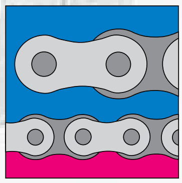
We are only satisfied when you are.

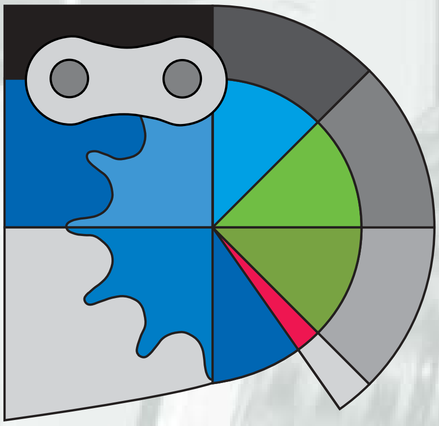
We have created the conditions for this by means of intensive consulting, partnership and our own sales activities. Thus there is a combination of our market know-how, technical competence, customer service and the satisfaction of our customers.



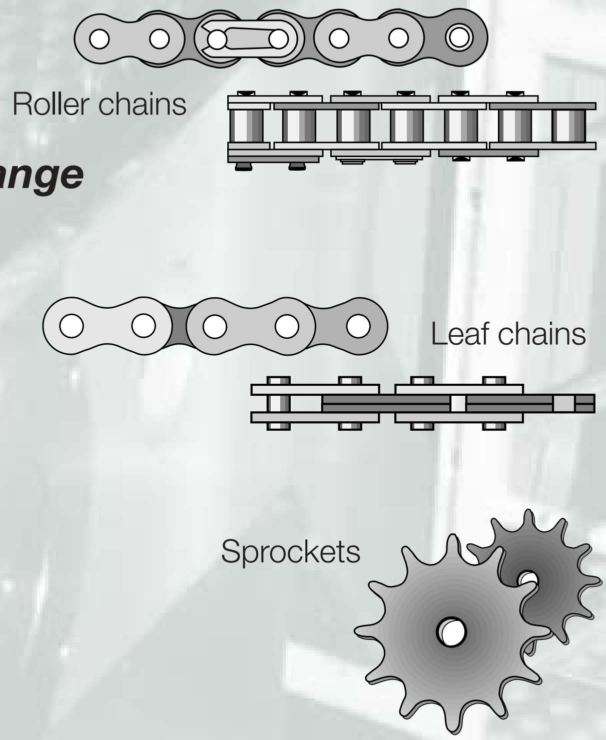








Product range



Competence

As the manufacturer of one of the most extensive chain ranges for drives and conveying we are an established partner of leading companies. Our 5,000 chain variants provide an impressively large number of solutions and flexibility.

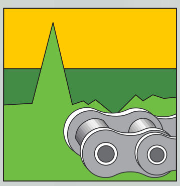
Innovation

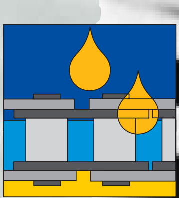
The secret lies in the production methods and the material.

Several thousand tools developed by ourselves rotate in the flow of production.
650 special tools were constructed by us for the manufacture of special chains.
30 special steels, alloyed, stainless, patented, are processed.
Moreover, we offer many different lubrications.
Through our customers we have become a specialist in surface refinement and the heat treatment of steel.

Quality

For Rexnord means that the customer comes back and not the chain.





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1 Fundamentals of the leaf chain

2 The mechanics of the leaf chain

3 Design of the leaf chain

4 Maintenance and lubrication

1.1 Design

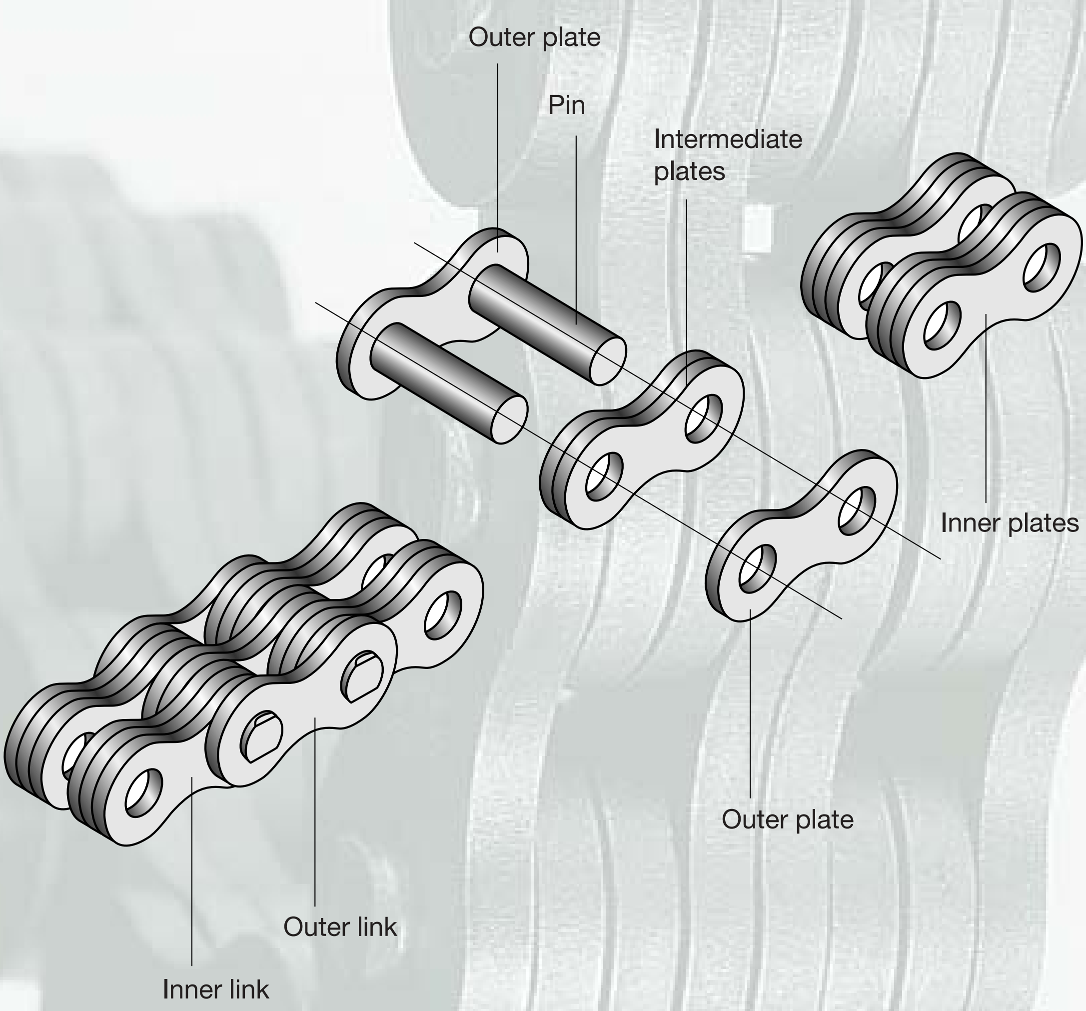
1.1.1 Construction

The leaf chain consists of link pins and plates. In the case of the plates a distinction is made between the outer, intermediate and inner plates.

The outer link of the leaf chain consists, in each case, of two link pins, the intermediate plates and two outer plates. They have a force fit. In addition, the link pins driven into the outer plates are riveted.

In order to make assembly possible the intermediate plates have a close sliding fit.

The inner link of the leaf chain consists, in each case, of the inner plates. In order to be able to ensure articulated movement the inner plates are provided with a close sliding fit.



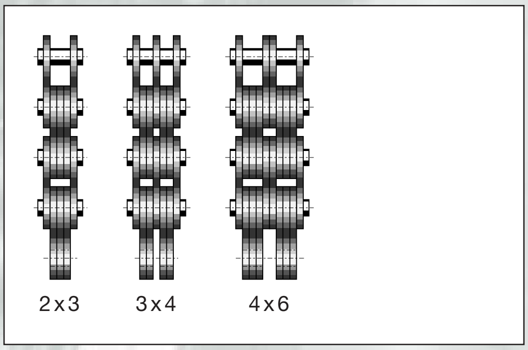
The leaf chain in detail.

In the case of the plate arrangements a distinction is made between:

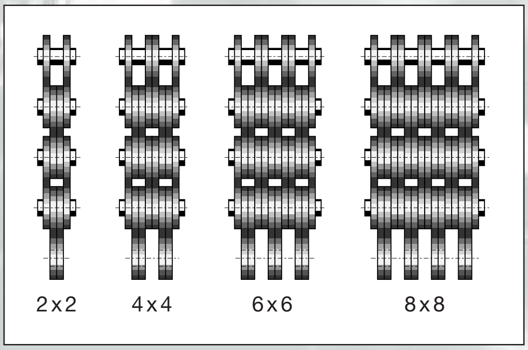
- Odd plate combinations,
- Even plate combinations.

Leaf chains with straight plate combination offer – with reference to the construction space required – a high breakage strength. On the other hand, leaf chains with an odd plate combination show an optimum fatigue strength and a larger link face (= resistance to wear)

(for further details on this see Chapter 2.3).



Odd plate combinations.



Even plate combinations.

1.1.2 Way of functioning

The leaf chain is, in principle, a load chain. As a rule it serves as a pulling device for the guiding of forces. It is used in conjunction with hydraulically actuated cylinders or as a counterweight chain.

The leaf chain is not suited to running over toothed sprockets and transferring a torque to them.

The most widespread use of the leaf chain is in the lift masts of fork lift trucks. It also performs an important function as a counterweight chain in machine tools, and also as a lifting chain in container lift-trucks.

1.1.3 Materials

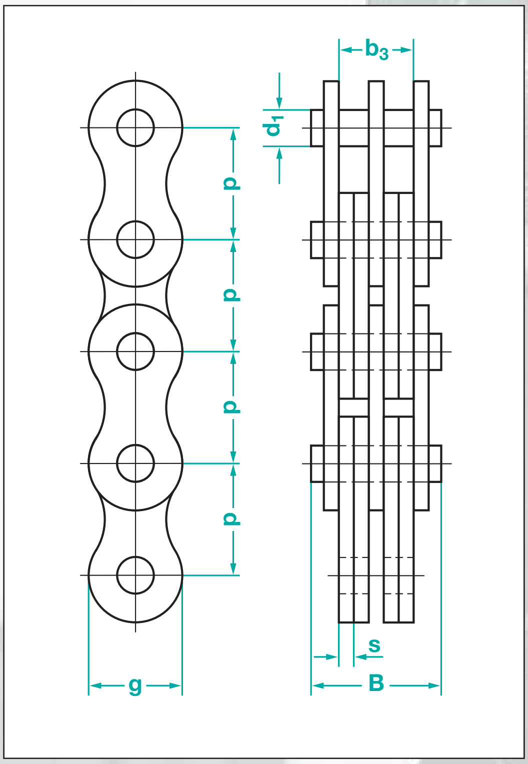
Plates:

The link plates are made of tempered material and heat treated, i.e. they are through-hardened and then annealed again in order to obtain a tough structure.

Pins:

These are, depending on requirements and area of use, made of hardened steel or case-hardened steel.

While pins of hardened steel undergo a very great and uniform increase in strength over the whole cross-section in the course of heat treatment, in the case of the case-hardened link pins there is a marked graduation between core hardness and surface hardness. Case-hardened pins have a core of medium strength and in addition a surface (skin) with outstanding hardness.



The most important dimensions.

1.1.4 Dimensions

The main dimensions of a leaf chain are determined by the pitch (p) and the plate combination. Moreover, the plate thickness (s), plate height (g), pin diameter (d_1) and overall width (B) as well as the connecting dimension (b_3) are of importance.

1.2 Types of construction and fastenings

1.2.1 Types of construction / standards

As a matter of principle four types can be distinguished between:

"AL" type – light series – (not standardised)

This is a type based on the roller chains of the ANSI series (DIN 8188). Plate contour, thickness and pin diameter are identical to the roller chains of the same pitch.

In the case of the AL type straight plate combination are usual (see "Quality chains" catalogue, page 33).

"BL" type – heavy series LH – (DIN 8152, Part 3 / ISO 4347)

This series is also derived from the roller chains of the ANSI series (DIN 8188), the plate contour corresponding to the roller chain of the same pitch, but the plate thickness and pin diameter corresponding to the roller chain of the next larger pitch. They are therefore extraordinarily compact and provide – with reference to the overall space required – the greatest carrying capacity of all chains.

In the case of the BL type the even and odd plate combinations are standardised (see "Quality chains" catalogue, page 31).

"F" type – European series LL – (DIN 8152, Part 1 / ISO 4347)

This leaf chain series is based on components of the roller chains according to the European standard (DIN 8187). Plate and pin dimensions are identical to these.

In the case of the F type even plate combinations are standardised (see "Quality chains" catalogue, page 33).

"Works standard"

Leaf chains of this type meet specific criteria which standard chains do not meet.

If the use of chains of this series is considered, we recommend making use of our technical advisory service.

The leaf chains of the AL and F series are made up of roller chain components. In order to offset the pin / sleeve play, the pitch of the outer and intermediate plates of the roller chains is slightly smaller than the nominal pitch. The actual chain length of the AL and F leaf chains therefore deviates from the multiple of the nominal pitch.

The length data of the different chain types can be found on pages 31 to 33 in our "Quality chains" catalogue.

The admissible length deviation of all leaf chains is based on this length dimension and, in the case of the dry, unoiled chain, under measuring load, is ±0.25 %.

1.2.2 Coding

The designation of a leaf chain can be decoded as follows:

Letters

The letters used as a prefix for the leaf chain indicate the series:

AL – light series

BL – heavy series LH
(DIN 8152, Part 3 / ISO 4347)

F – European series LL
(DIN 8152, Part 1 / ISO 4347)

Digits / Numbers

The digits and / or numbers indicate the plate combination and chain pitch:

Last digit
– Number of inner plates

Last but one digit
– Number of outer and intermediate plates

The chain pitch is coded by the remaining number. The coding is different for the series:

AL and BL series
– pitch in ⅛" (25.4 mm)

F series
– pitch rounded up / down in mm

Example 1:

BL 6 2 3

3 inner plates

2 outer plates

pitch = 6 · ⅛" = ¾" = 19.05 mm

heavy series LH

Example 2:

F 50 - 4 4

4 inner plates

2 outer plates
and 2 intermediate plates

pitch = 50.8 mm

european series LL

Example 3:

AL 10 6 6

6 inner plates

2 outer plates
and 4 intermediate plates

pitch = 10 · ⅛" = 1¼" = 31.75 mm

light series

1.2.3 Connecting elements

Chain anchor:

As a rule, leaf chains – starting and ending with inner links – are fastened with the help of chain anchor and / or block-end links. The free inner plates of the leaf chain engage in appropriate recesses in these fastening elements and are taken up by a pin which has the same diameter as the link pin.

(For dimension recommendations see the catalogue "Quality chains", page 35)

For reasons relating to assembly technique and to operational reliability connecting of a chain by means of outer plates should be refrained from.

Assembling pins:

As assembling pins preferably those of hardened steel with a minimum strength of 1,200 N/mm^2 should be used.

(See the catalogue “Quality chains”, page 34)

Plate-end links:

Plate-end links have both a larger bore hole and a larger pitch. They permit simple and easy fastening of the leaf chain to machine components of lower strength.

(See the catalogue “Quality chains”, page 36)

1.2.4 Deflection rollers

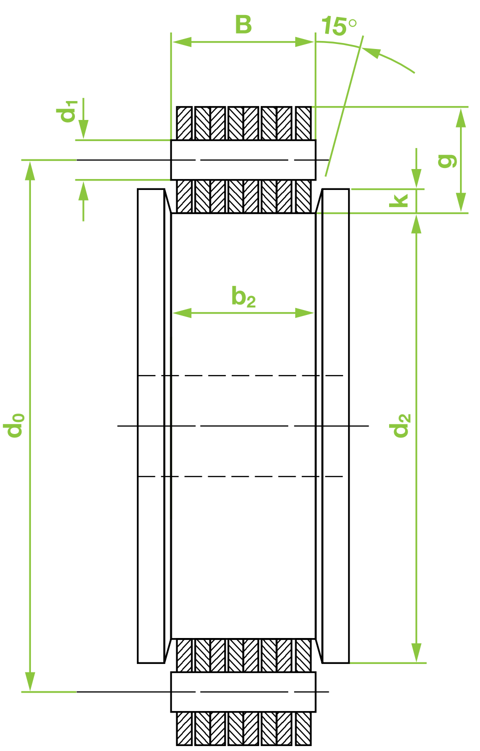
Leaf chains can be guided over untoothed deflection rollers. The deflection rollers should have the largest possible diameter. The diameter of the deflection roller determines the size of the link movement at the chain inlet and outlet, and thus also to a considerable extent the wearing life-span of the chain. Moreover, a large deflection roller diameter contributes to smooth running of the chain.

Dimensions of deflection rollers:

The diameter of deflection rollers should as far as possible be 5 times, but at least 3 times the chain pitch.

The width of the running face, B, in the case of a deflection roller should correspond to the leaf chain width across the rivet pin.

The flanged wheel height “k” is selected 15 % smaller than corresponds to the distance between the plate upper edge and the rivet pin.



Structural type of the deflection roller.

$d_2 = 5 \cdot p$; min $3 \times p$
$d_0 = d_2 + g$
$b_2 = B$
$k = 0.43\,(g - d_1)$

d_2 = running face diameter
d_0 = reference diameter
b_2 = runnig face width
k = flanged wheel height

p = chain pitch
g = plate height
d_1 = rivet pin diameter
B = leaf chain width across rivet pin

The corresponding dimensions for the series F (LL) and BL (LH) can be seen from the catalogue “Quality chains” (pages 31 to 33).

In order to prevent premature wearing on the running face of the deflection rollers and so as to avoid deformations on the running face, it is recommended that the rollers be hardened to a tensile strength of 1,200 to 1,500 N/mm² or, however, that the surface be hardened by inductive and/or flame hardening of the surface up to a maximum of 55 HRc. A starting material with a minimum core strength of 490 N/mm² should be selected.

Rexnord leaf chains with plastic protective plates can be fitted on deflection rollers without flanged wheels. If the protective plates are arranged on both sides externally they handle the lateral guiding on the deflection roller.

If, on the other hand, the leaf chain is fitted with a centrally arranged protective plate, this engages in an appropriate recess in the centre of the deflection roller and thus ensures lateral guiding.

Running behaviour:

The smaller the deflection roller diameter is, the larger is the multiple polygon effect. This means, for example, in the case of a fork-lift truck, that with an even, constant lifting movement of the hydraulic piston the lifting movement of the chain, during the unwinding of the individual chain links on the deflection roller, is imparted an uneven movement.

If one compares the size of this unevenness between a deflection roller diameter of 3 times the chain pitch with that of 5 times the chain pitch, the smaller roller diameter shows a percentage speed deviation of 4 % based on a uniform lifting movement of the hydraulic piston.

At a value of 5 times the chain pitch for the deflection roller diameter, the uniformity difference amounts to only 1.1 %. If the ratio of these two values is formed it can be seen that the smaller diameter causes 3.6 times the variation in the lifting movement of the chain. This naturally leads to the lifting movement of the chain being noticeably jerky under full load in the case of the small roller diameter.

This is disadvantageous for the functioning of the equipment but also for the chain wear. This is thus exposed to unnecessarily high additional dynamic loads. At extremely high permanent loads this can, in certain cases, lead to premature fatigue fracture (endurance fracture) of the chain.

Wear characteristics:

If one compares the wear characteristics of a chain at a deflection roller diameter of 3 times the chain pitch with one of 5 times the chain pitch, the leaf chain at a larger diameter experiences a 50 % lower link movement when entering and leaving the deflection roller.

This means a wearing life-span increase of 50 % also for the roller diameter 5 times the chain pitch.

In order to optimise the running characteristics of the leaf chain and its operational reliability as well as the high uniformity of the lifting movement it is recommended, in the fork-lift truck business, that deflection roller diameters of 4 to 4.5 times the chain pitch be selected. This also improves the wearing life-span considerably.

In the case of the use of leaf chains in machine tools as well as in general mechanical engineering, for the above-mentioned reasons deflection roller diameters of 5 to 7 times the chain pitch are used.

1.3 Fields of use

1.3.1 Fork-lift trucks

For fitting in fork-lift trucks, the BL series is most suitable. BL leaf chains are of extraordinarily compact construction. They have pins with relatively large diameters. This permits the linking of chains directly to chain anchors.

The use of plate-end links is not necessary. As a result a significant saving is achieved during the assembly of the chains in mast production.

BL leaf chains make possible, due to their compact structural shape with, at the same time high carrying capacity, the avoidance of large plate combinations such as 6 x 6 and 8 x 8. The disadvantages of these combinations will be described in more detail in Chapter 2.3.

Rexnord leaf chains with plastic protective plates (works standard chain “KS”) provide outstanding characteristics for use in fork-lift trucks.

The plastic protective plates protect the piston rod, the hydraulic cylinder and the mast from damage.

AL and F leaf chains should be avoided in the case of new designs for fork-lift trucks.

1.3.2 Machine tools

Leaf chains of the F series are particularly suitable for use in machine tools.

The choice of material and the heat treatment were tailored to the above-mentioned areas of use. Chains of this type have a very high resistance to wear.

However, here too, the recommendation applies of dispensing as far as possible with the use of plate combinations such as 6 x 6 and 8 x 8.

If leaf chains never have the pressure taken off them at any time during use – as this is typical of use as a counterweight chain in machine tools – regeneration of the grease film in the link area is made very difficult. In these cases such leaf chains require special treatment in the link area. We therefore recommend that the key words “Machine tool chain” be given in the purchase order.

If in such cases a standard leaf chain is used, slip / stick effects (sliding-back), noise development and possible cold welding on the chain links cannot be excluded.

Leaf chains in use in a fork-lift truck (left).
Leaf chains (2 x F 76-66) in a machine tool (right).

1.3.3 General mechanical and apparatus engineering

If leaf chains experience a large number of load cycles, and/or link movements and if high resistance to wear is a primary objective, the F leaf chains are particularly suitable.

If extremely high impact loads occur, the BL leaf chains offer advantages with regard to fatigue strength and operational reliability.

Make use of the experience of our application advisory staff.

Leaf chains in a telescopic crane.

1.3.4 Low temperature

Rexnord leaf chains are produced with particularly cryogenic steels. They have a high notched bar impact value and fatigue strength. The drop in these values at low temperatures of down to – 40 °C is so slight that limitations need to be taken into consideration neither for design nor for practical use.

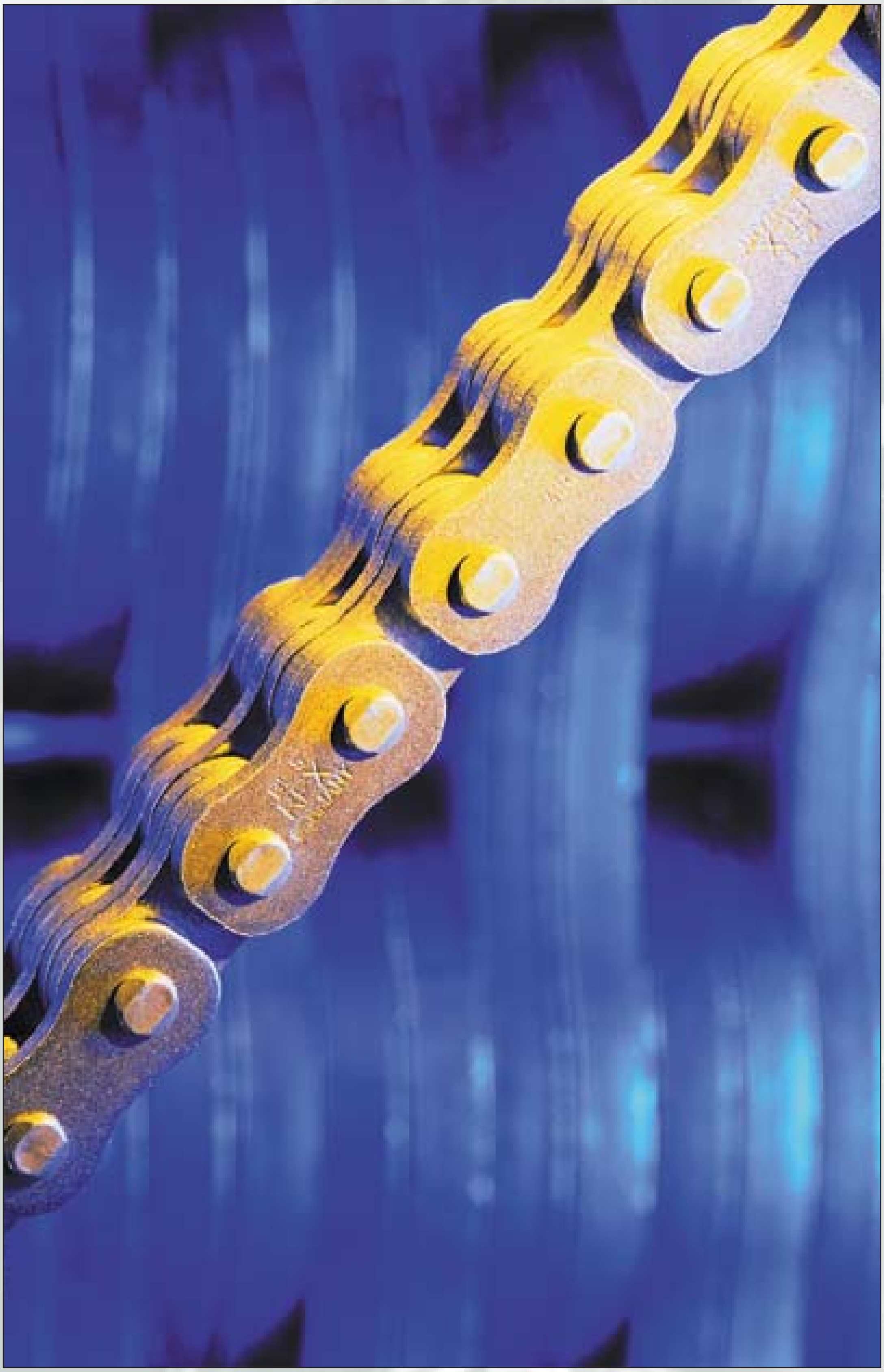
It is necessary for use in this case to provide the chains with an oil which retains its full lubricity in the given temperature range. It is important for the ex-works lubrication to already meet this requirement. This is to be taken into account in the purchase order.

If leaf chains with standard greasing are used no adequate lubricity is shown. The grease is considerably too stiff at the given temperature for the particular use.

Later re-lubrication with a suitable oil does not produce a solution, either, as it cannot find any access to the lubricating points.

1.3.5 Special applications

Get in touch with us. We look forward to finding a solution together with you.



2.1 The total load of the leaf chain

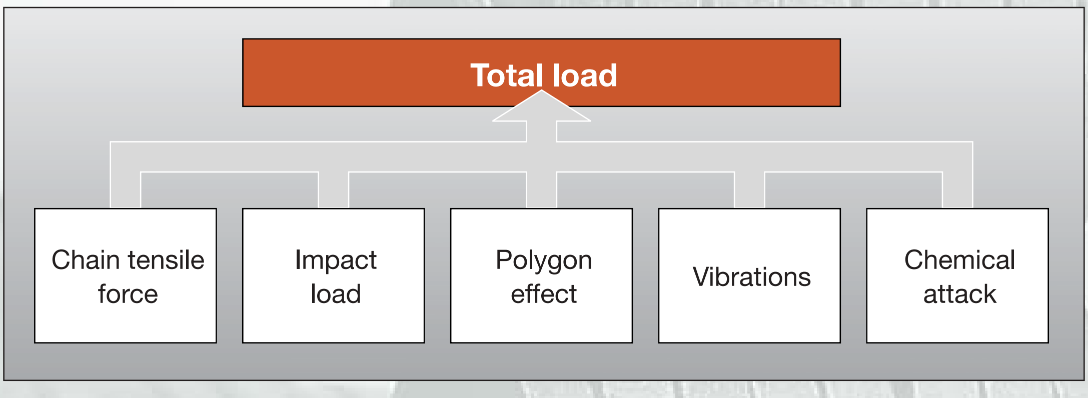
The total load of a leaf chain as a lifting element is the total of all the individual loads such as chain tensile force, impact load and the dynamic loads occurring which are caused by vibrations and polygon effect. See following illustration.

The overall load has a two-fold influence on the service life of the chain:

On the one hand via the fatigue strength and, on the other hand, via the resistance to wear.

In order to optimise the two quality factors of resistance to wear and fatigue strength in the case of the load diagram shown, Rexnord chains are produced with special manufacturing processes (see Chapter 2.4).

The total load of the leaf chain.



2.1.1 Chain tensile force

The chain tensile force can be determined by the mass to be lifted (e. g. in the case of a fork-lift truck: goods conveyed, fork weight, moving mast part, …) and by the number of chain strands used.

2.1.2 Impact load

Impact loads are produced by extreme accelerations and retardations of the lifting chain or introduced from outside into the system (e.g. during driving of a fork-lift truck over uneven ground).

2.1.3 Polygon effect

Uneven movement of the leaf chains caused by the "polygon effect" of excessively small deflection rollers (see Chapter 1.2.4).

2.1.4 Vibrations

High-frequency vibrations can be generated by independent exciters (e. g. in the case of machine tools). Likewise, in the case of fork-lift trucks, severe chain vibrations can occur in certain driving states.

2.1.5 Chemical attack

By the influence of acids, chlorine, caustic liquids and free hydrogen, hydrogen embrittlement of the chain components of hardened material can be caused and the operational reliability and the chain service life can be considerably reduced.

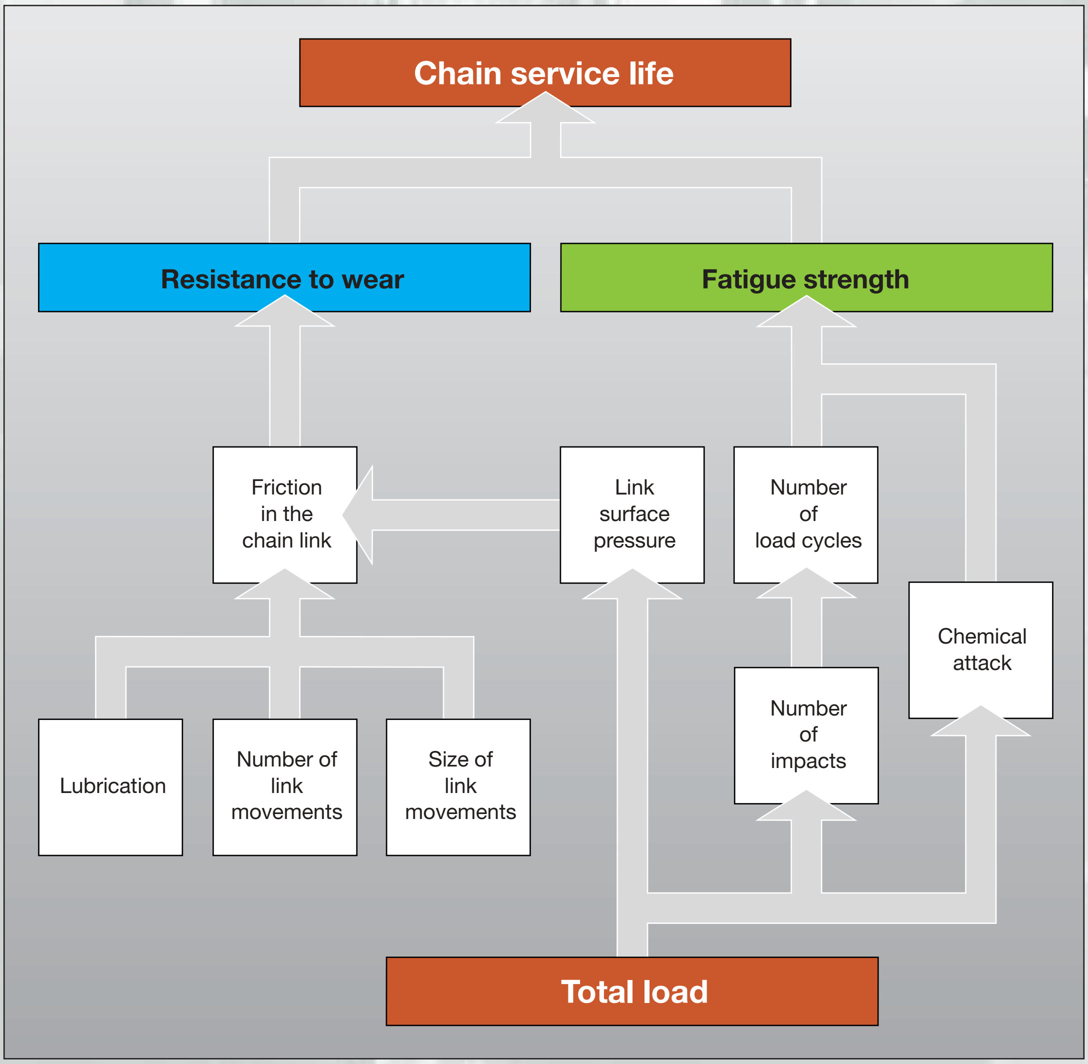
Since this damage frequently occurs during cleaning of the leaf chains, this subject will be dealt with in detail in Chapter 3.2.4 "Cleaning".

2.2 Influencing factors on the determination of service life

The statutory regulations demand, for the checking of a lifting chain, only the static safety of the chain breaking force.

As the load in the application is dynamic and not static, this way of considering the problem is not in line with actual practice.

Below, the real influencing factors are shown:



Influencing factors in determining the service life.

2.2.1 Resistance to wear

The wear of a chain is caused by the friction between pins and inner plates in the chain link.

The friction is influenced by the following factors:

■ **Link surface pressure:**

It is the quotient of chain tensile force and link surface area.

The link surface area is a mathematical variable. In the case of leaf chains it represents the surface area of the chain pin projected onto the inner plate bore holes. That means that it is the product of the pin diameter (d_1) of the plate thickness (s) and the number of moving inner plates. The value for the link surface area can be found in our catalogue "Quality chains" on pages 31 to 33.

Due to the limited pressure absorption capacity of the lubricants a limiting of the admissible link surface pressure is necessary. Excessively high link surface pressures lead to mixed or dry friction as the lubricating film is displaced wholly or partially.

This, in turn, leads to the premature wear of the chain links and / or to the elongation of the chain, but also to pitting in the chain links.

A further consequence can be a chain defect:

- Twisted pins in the force fit of the plates
- Broken link pins
- Broken force fits in the outer plates

■ **Lubrication:**

Effective lubrication has a considerable influence on the wear life-span of a leaf chain.

Deficient lubrication can, lead, as well as to high link surface pressures, to premature damage to the chain. Due to the decisive influence you will find detailed information on this subject in Chapter 4 "Maintenance and lubrication".

■ **Number of link movements:**

These are directly dependent upon the frequency of the lifting cycles and the number of deflections.

■ **Size of the link movement:**

This is directly dependent upon the diameter of the deflection roller. The smaller the deflection roller is, the greater is the link movement and thus the wear on the chain (see Chapter 1.2.4 "Deflection rollers").

2.2.2 Fatigue strength

From the following load-extension diagram it can be seen that a chain does not become defective only when the breaking force point is reached, but that a permanent deformation occurs immediately upon the elastic limit being exceeded.

This leads to the destruction of the force fit connections between the outer plate and the link pin. The plate bore holes are subjected to oval widening. Thus the chain is destroyed.

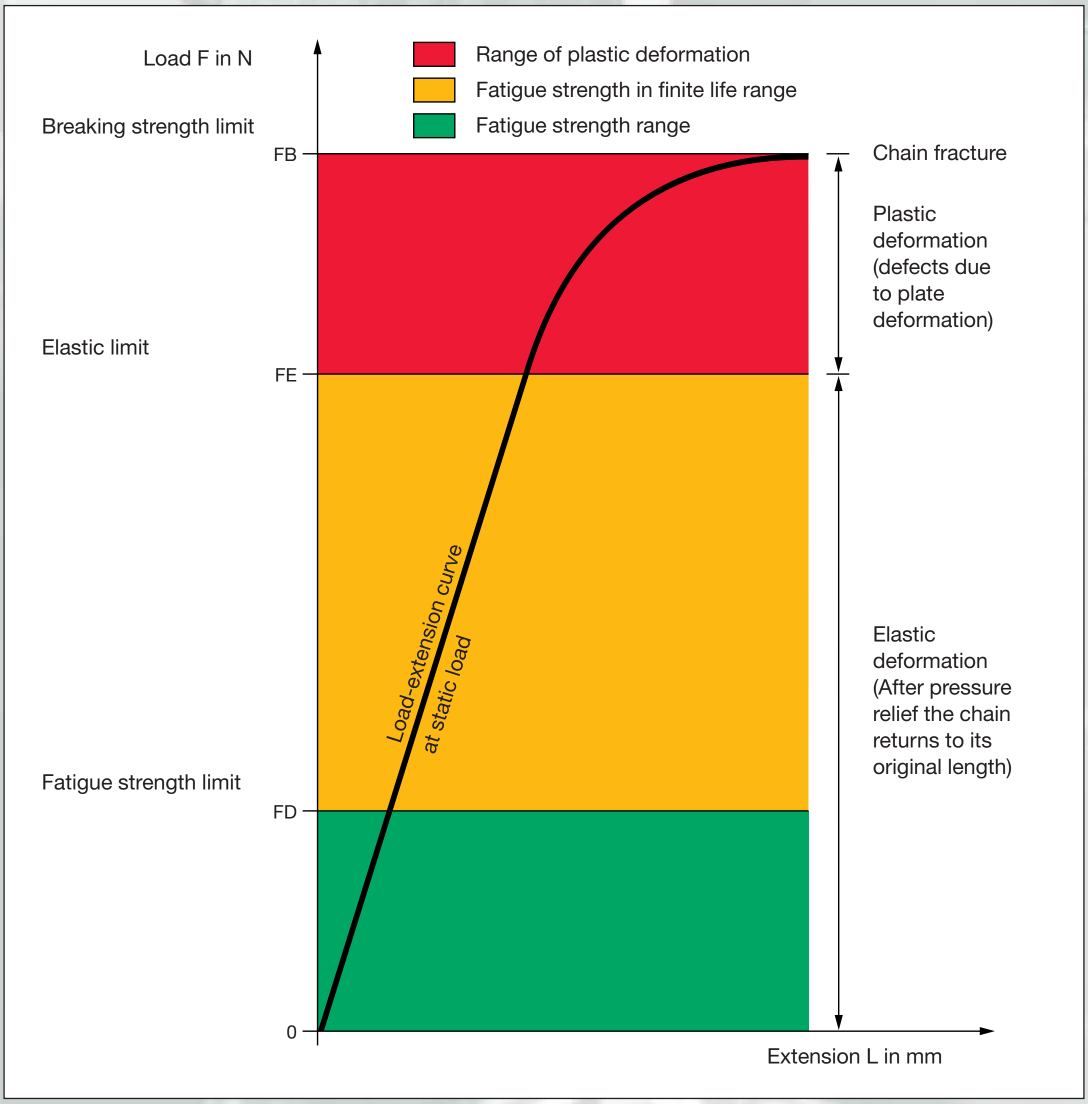
This process takes place long before the breaking strength point is reached. From these situations it becomes clear that for the direct failure of the chain it is not the breaking strength, but the elastic limit which is of importance.

For this reason Rexnord deliberately dispenses with the indication of high breaking strength values in the catalogues. Should, for the calculation of safety requirements, higher breaking strength values be required, we shall in the case of requirement be pleased to state our considerably higher effective values. Rexnord breaking strength data in the catalogues correspond to the standard specifications.

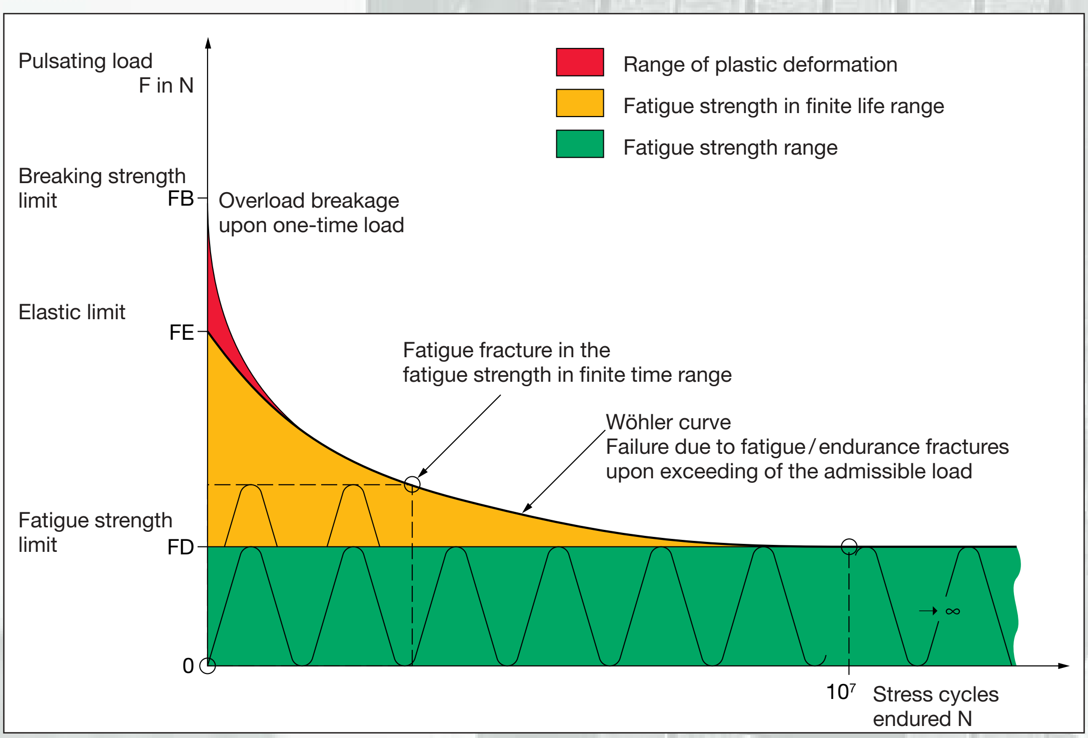
The fatigue strength for finite life indicates that range over which the chain survives for a limited period without fatigue rupture at the load occurring here. The lower the load applied to the lifting chain, the greater is the endurance achievable. If the load or a possibly occurring impact load is just below the elastic limit fatigue fractures (= endurance failures) can occur after several load cycles.

The feature of endurance failures is that they occur without deformation. The fracture pattern shows lines of rest. By this the development of the fracture progressing in stages can be seen. The residual fracture area remaining gives information about the level of the inadmissible load. A very large residual fracture area indicates that the overload or impact load was very high.

If the loading of the chain – caused by chain tensile force, polygon effect and vibrations – occurs exclusively in the fatigue strength range and if the impact loads - in number and size - are in the fatigue strength in finite life range, in the case of proper and correct operation any kind of chain defect – overload breakage and fatigue fracture – is excluded. The life-span of the chain is then determined exclusively by its resistance to wear.



The different load areas of a leaf chain.



The fatigue strength diagram according to Wöhler.

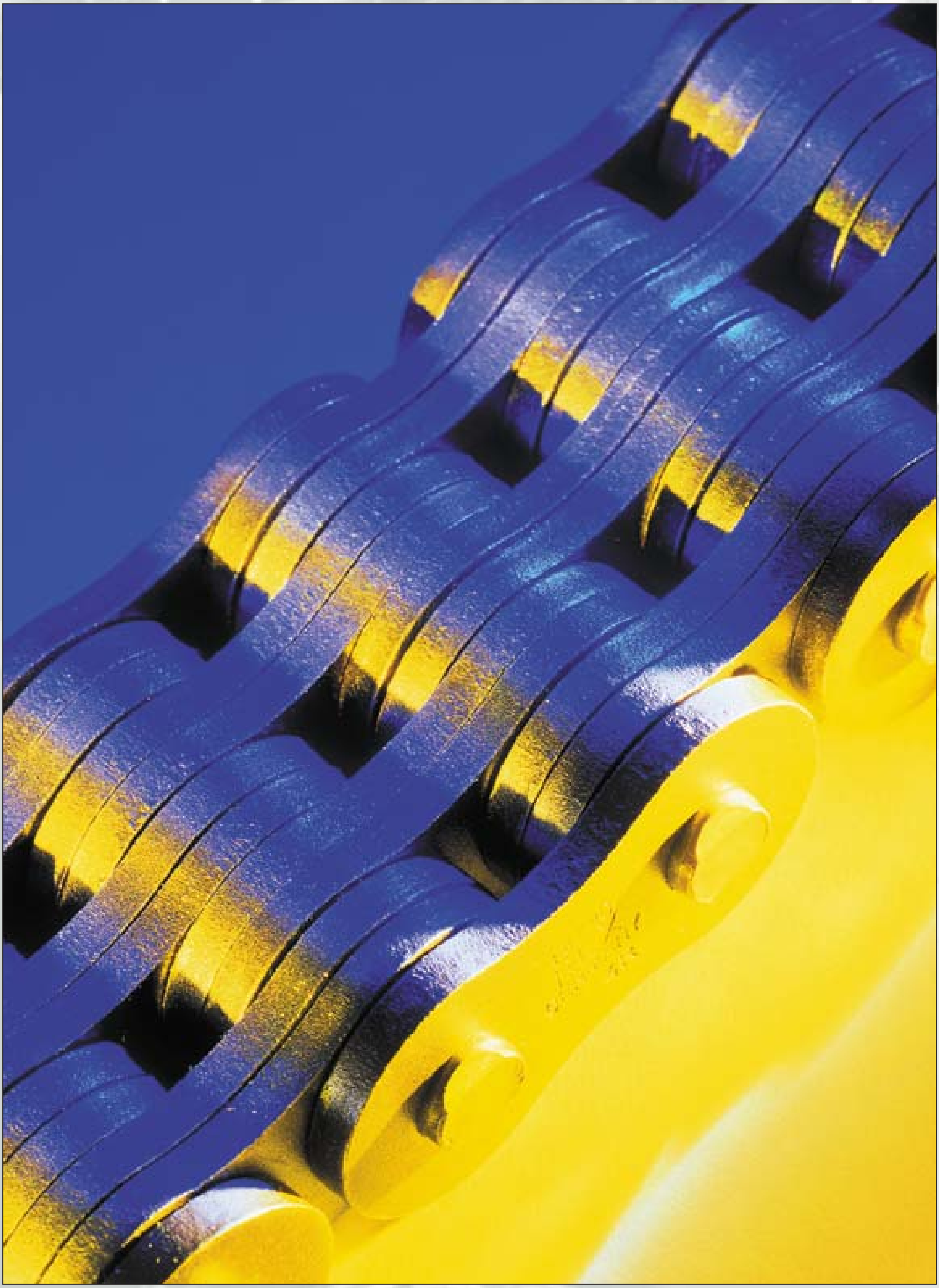
The fatigue strength of a lifting chain is the decisive value for operational reliability.

What use is a long wearing life-span if the leaf chain fails as a result of fatigue fractures before this wearing life-span is reached?

The fatigue strength is that maximum load value which the chain only just continuously bears as a pulsating stress, without failing as a result of fatigue fracture.

Fatigue stresses up to the fatigue strength limit are withstood with an unlimited number of stress cycles endured (→ ∞).

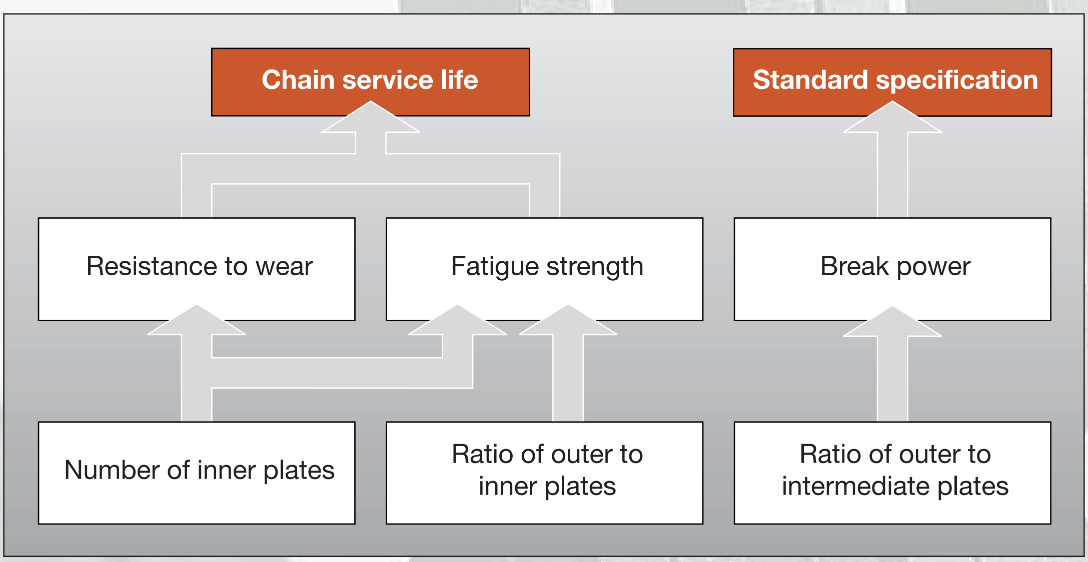
For the practical carrying-out of the tests first of all considerably higher load values are run than correspond to the fatigue strength to be expected.All the figures obtained are entered on the diagram. With falling load values the number of stress cycles endured gradually increases until finally a fatigue-tested specimen without rupture is obtained, i. e. more than 10 million load cycles are achieved (10 million = 10^7).



2.3 Influence of the plate combination

Besides the manufacturing quality the plate combination of the leaf chain has a considerable influence on the suitability for a certain application.

The actual chain service life is determined by the resistance to wear and the fatigue strength. Whereas the standard specification only takes into account the breaking strength.



The effect of plate combination on chain service life.

2.3.1 Resistance to wear

As described in Chapter 2.2.1 the inner plates and the link bolt form the chain link. Thus the resistance to wear is in a direct ratio, and in fact proportionally, to the number of inner plates.

The outer and intermediate plates have no influence on the resistance to wear.

2.3.2 Fatigue strength

2.3.2.1 Influence of the inner plates

The outer plates of a Rexnord leaf chain are fitted to the chain pins with a high force fit. The inner and intermediate plates show a close sliding fit. (See Chapter 1.1.1).

For the task of the force fit in the outer plate, which is to secure the pin radially and axially, the force fit must build up a tension field in which the absolute value is always lower than that value which is produced by the tensile force.

This high pre-stress in the outer plate increases the fatigue strength of the outer plate immensely, i. e. the outer plate has, in relation to fatigue strength, a considerable advantage as compared with the inner and intermediate plates. This advantage is so great that even in the case of a leaf chain with the plate combination 4 x 6, the six inner plates determine the fatigue strength of the chain. In the case of yield strength tests this characteristic is confirmed - it is always the inner plates that fail as a result of fatigue fractures.

The yield strength of the leaf chain, however, does not rise in proportion to the number of inner plates.

The cause of this is to be seen in the fact that with rising plate combination the load distribution becomes increasingly uneven, i. e. less defined. This circumstance can be explained by the fact that all the chain components show a certain tolerance and that under load pin bending is possible.

Here it must be remarked that the high fatigue strength achieved at Rexnord – in comparison with other chains - is attributable to, among other things, the high precision of the individual parts.

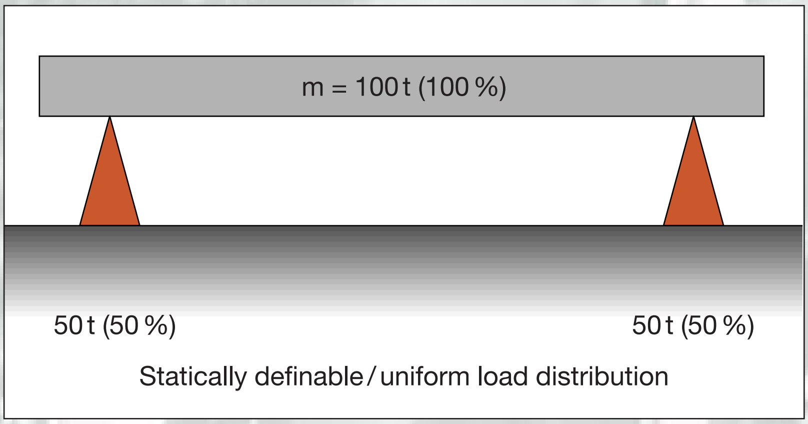
While a leaf chain with the plate combination 2 x 2 experiences a load distribution over two chain plates and thus represents a “statically definable system”, in the case of leaf chains of larger plate combination many chain plates are involved in the load distribution. This then represents, from a technical point of view, a “statically indefinable system”, as the load distribution is very highly dependent on precision and elasticity.

Please note the following sketches.

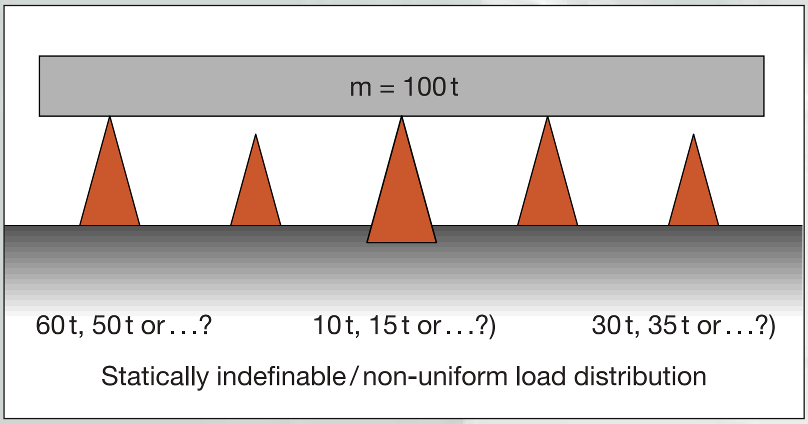
The influence of the number of plates can be seen from the fact that chains of equal breaking strength and quality with the plate combination 2 x 2, seen in comparison, show a more than twice as high a fatigue strength than leaf chains with the plate combination 8 x 8.

Important:

This representation makes it clear that the size of the plate combination, the precision of the plate bore holes and a close tolerance in the pitch dimensions primarily determine the load distribution over a chain and thus its fatigue strength (stability under load).



Load distribution in a schematic representation in the case of a symmetrical system, e. g. leaf chains with plate combination 2 x 2.



Load distribution in the case of leaf chains of larger plate combination in a schematic representation.

2.3.2.2 Influence of the ratio of outer to inner plates

The ratio of outer to inner plates does not have any direct influence on the fatigue strength of the leaf chain in the state as new. However, it influences the operational reliability under difficult maintenance and lubrication conditions or at extremely high loads.

As already mentioned, the force fits of the outer plates ensure the rotational locking of the pins, the fixing with regard to lateral displacement and to optimisation of the fatigue strength.

In the case of defective lubrication and at extremely high stresses, which lead to a link surface pressure above the Rexnord recommendations, the lubricating film in the chain link – between pin and plate bore hole – is repeatedly broken through during the lifting movement. This leads to what is known as mixed friction and to cold welding between the pin upper side (load side) and the moving plates of the inner link. During deflection under load the inner plates thus produce an enormously high torque on the chain pin.

If now the pre-tension generated by the forced fit in the two outer plates is overcome, the pin in the outer plates rotates.

If the pin now rotates through approx. 180 °, the original load side with its scoring comes into a position facing away from the load. In every load now following the notch-damaged surface is no longer located in the pressure zone of the pin surface, but in the tensile zone. Fractures, starting from the notches and/or scoring are the inevitable consequence.

Leaf chains with twisted pins are no longer operationally reliable!

The greater the plate combination, the more unfavourable does the ratio of plates turning on the pin to those which secure the pin against axial and radial torsion become.

Every leaf chain has only two outer plates with force fits!

The practical comparison:

Leaf chain with plate combination 2 x 2:

2 inner plates exert the torque on the pin.
2 outer plates counteract this torque.
Qualitative force ratio: 2 to 2 = 1

Leaf chain with plate combination 8 x 8:

8 inner plates exert the torque on the pin.
2 outer plates counteract this torque.
Qualitative force ratio: 8 to 2 = 4

At the same specific link surface pressure, maintenance and lubrication, the inner plates of a leaf chain exert a four times higher torque on the chain pin than the inner plates of a leaf chain 2 x 2.

For both plate combinations, however, the counteracting torque, which is generated by the force fit in the outer plates, is the same.

In practical use a leaf chain with the plate combination 2 x 2 is more than four times more robust than a leaf chain with the plate combination 8 x 8 as additively the non-uniform load distribution also exerts a negative influence in this case.

2.3.3 Breaking strength

As can be seen from the following load-expansion diagram, the expansion characteristic curve first passes through the area of elastic deformation. Here a temporary extension proportional to the load is obtained. In this area a slight load convergence of the individual plates in the same plate package exists. If now the load in the breaking test is further increased, the extension characteristic curve passes through the area of plastic or permanent deformation.

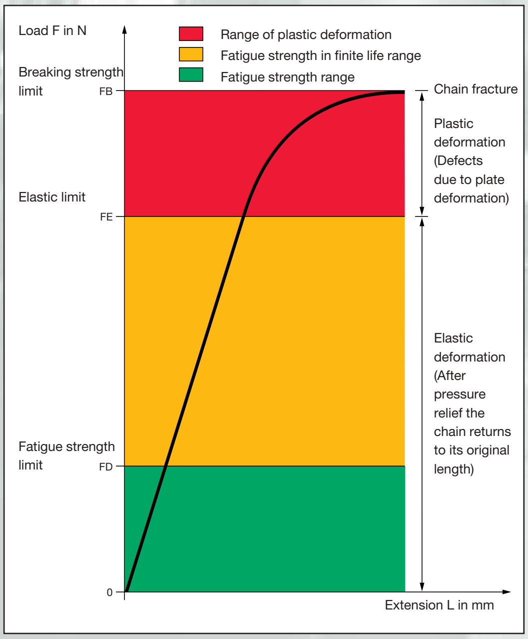
Through the plastic deformation of the initially "shorter" plates a load balancing successively takes place. This takes place regardless of the size of the plate combination.

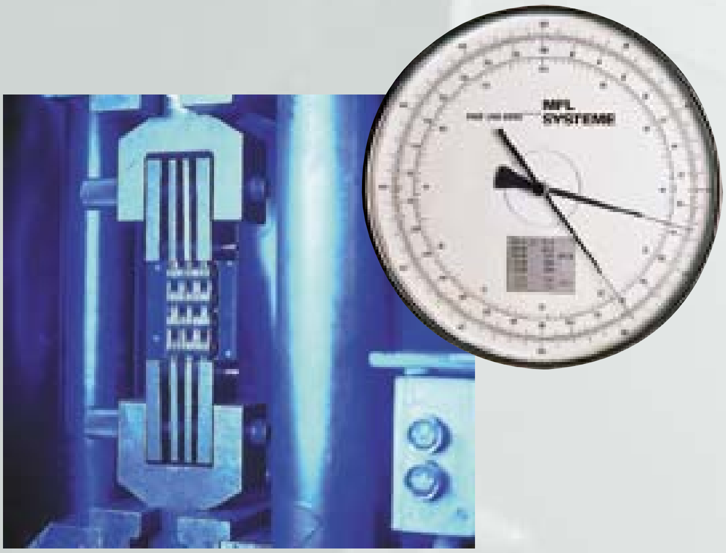
The breaking strength (rupture value) of a leaf chain rises as a straight line with the number of the outer and inner plates, since at loads above the elastic limit all the plates carry to the full extent (see Chapter 2.2.2 "The different load areas of a leaf chain").

Neither in the fatigue strength test, nor in practical use do the chain plates experience a load in the plastic range. Permanent deformation does not occur. Thus, however, the non-uniformity of the load distribution is also retained.

Also these facts shown indicate that a breaking strength value and/or a statistical safety factor based on it can never make a statement about the true suitability of the chain to be used.

Only the fatigue strength offers this possibility.



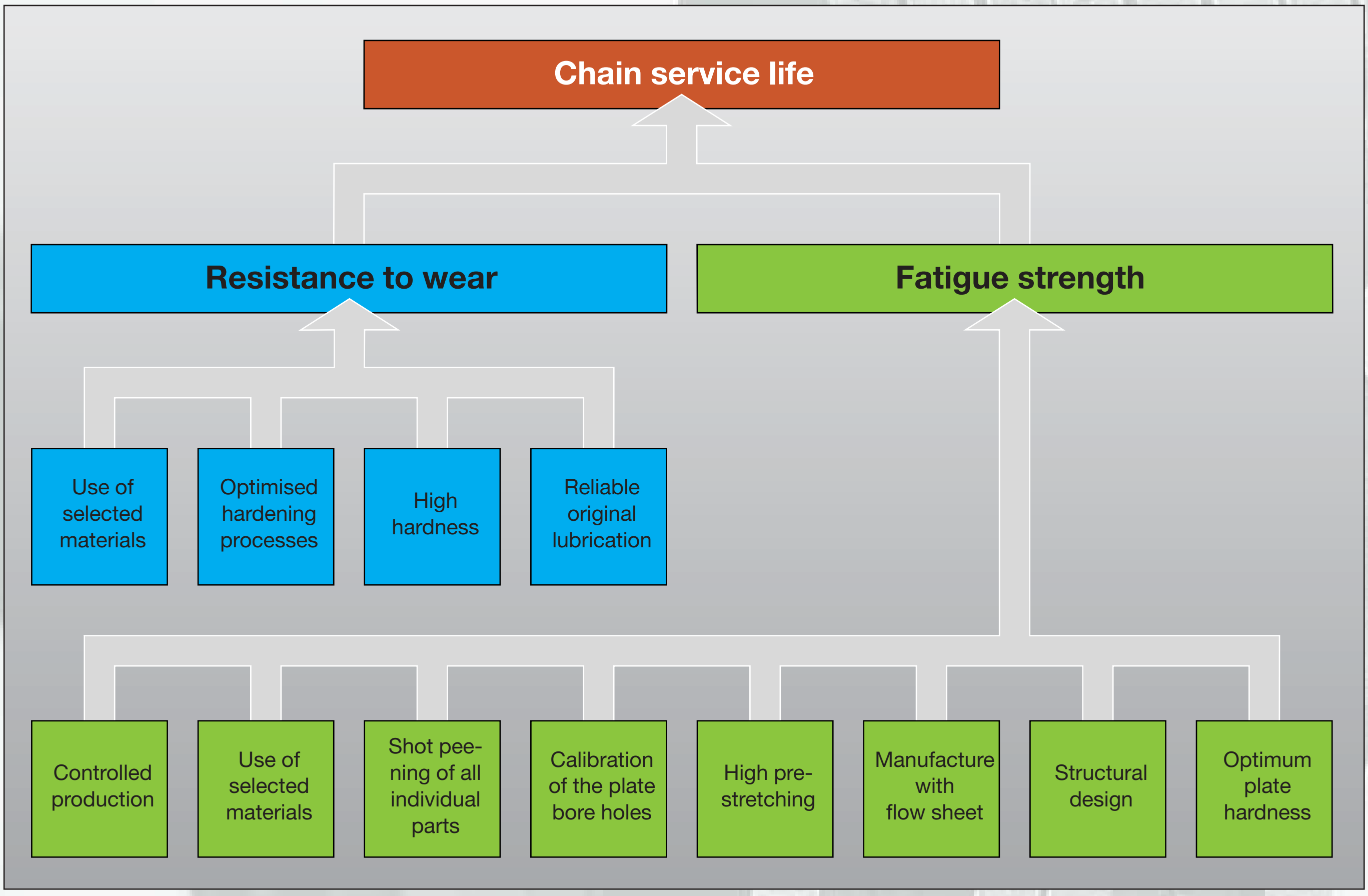


2.4 Rexnord manufacturing processes

Safety element lifting chain

Lifting chains in industrial trucks and in other lifting devices are safety elements. In order to reliably meet the high demands made on safety elements, process safety and reliability in the manufacture of individual parts and the assembly of Rexnord leaf chains are given top priority.

In order to optimise the two quality factors of resistance to wear and fatigue strength, for the production of Rexnord leaf chains the following manufacturing processes are systematically used:



Rexnord production procedure to optimise the chain service life.

2.4.1 Controlled production

- Systematic tests in the manufacturing phases.
- Monitoring of the automatic assembly machines with optical and laser-optical inspection systems.
- Strict monitoring and control of heat treatment.
- Secured processes in every manufacturing step.

Photo-optical control.

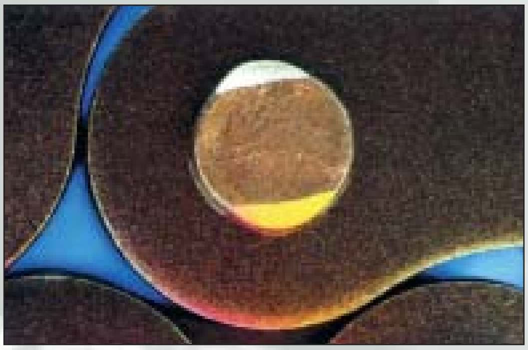
2.4.2 Use of selected materials

- Exclusive use of special steels.
- Material specification according to exact Rexnord specifications.
- As compared with the standard type delimited carbon content.
- Strongly delimited tolerance field for basic material strength.
- Cold-rolling steps in accordance with specified Rexnord sequence plan.
- Considerably reduced share of undesirable steel additives.
- Delimited tolerance fields with regard to dimensions.
- Purchase of only certified, tested and reliable suppliers.
- Assessment and supply involvement according to the Rexnord assessment system.
- Delivery of all materials with certificate and analysis certificate.

Storage of special chain steels.

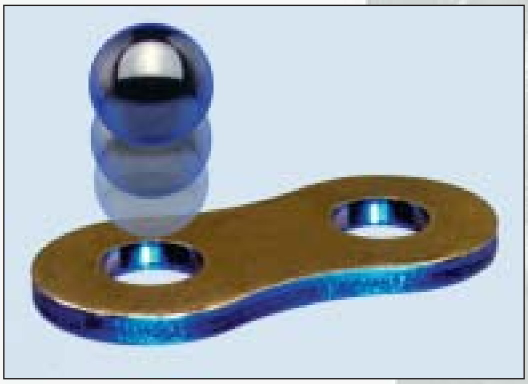
2.4.3 Shot peening

Shot peening is an effective cold treatment, which additionally solidifies the surfaces of the individual chain components and produces a high internal pressure stress.



Shot peening.

Ball calibration.



The load carrying ability and the fatigue strength are markedly increased by this.

2.4.4 Calibrating of the plate bore holes

By the calibrating of the plate bore holes a cold hardening of the material is achieved. Moreover, the calibrating process ensures close tolerances of the bore holes and thus ensures the creation of the conditions for optimum force fit within a narrowly defined frame. At the same time the scoring and sharp edges are eliminated. This brings about an enormous improvement in the fatigue strength.

Before and during pre-stretching

2.4.5 High pre-stretching

Rexnord BL leaf chains are “high pre-stretched”. From this high pre-stressing a considerable improvement of the load distribution between the individual chain plates results. This thus considerably increases the fatigue strength.

2.4.6 Manufacture with flow sheet

Rexnord leaf chains are fitted with the batch identification introduced by us. The batch number (“silver label”, as the batch number is applied to a galvanised plate) makes possible the retracing of all of the tests laid down in the manufacturing process as far as the raw material and its suppliers. The test results are kept for at least ten years and can be inspected as required.

Chains with silver label.

2.4.7 Structural design

For the efficiency of a chain plate not only the “endangered cross-section” in the top area is of great importance, but also the plate waist, since under load the stresses extend into this area. Rexnord chain plates show a very wide plate waist. The “Rexnord plate shape” produces the largest possible fatigue strength value with reference to the given limit values for plate height and of the other design parameters such as plate thickness, top camber, material strength and manufacturing methods.

2.4.8 Optimum plate hardness

The Rexnord plate hardness is a balanced compromise between a high tensile strength and elasticity.

A high hardness (tensile strength) is of importance for the construction of an optimum force fit and for a high resistance to wear of the leaf chain (the inner plates together with the pin form the chain link). However, if the hardness exceeds a certain value, the chain plate becomes too brittle, the fatigue strength drops off dramatically and the sensitivity to aggressive media (free hydrogen, acids, …) and corrosion decreases markedly.

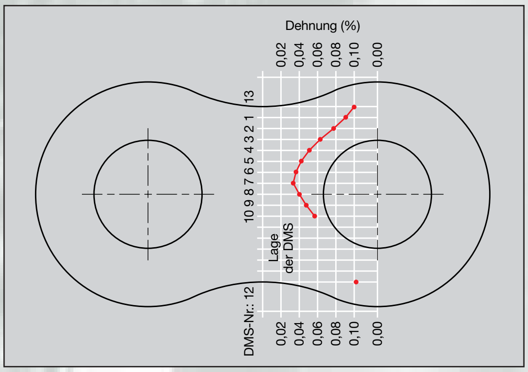
2.4.9 Optimised hardening process

- Heat treatment in new, modern and reliable hardening units
- Heat treatment in separate batches.

2.4.10 Reliable original lubrication

The reliable original lubrication is the basis for a good protection from wear and corrosion.

Rexnord offers a large number of special lubrications tailored to your special case of use. You will find more on this in our catalogue “Quality chains” on pages 48 and 49.



Measurement of stress on the inner plate by means of rotary measuring strip.

Link plate during Rockwell hardness measurement.

Hardening through heat treatment.

Original lubrication.

3.1 Introduction

For the design of lifting chains a number of points are to be observed:

1. Meeting of the technical specifications of the machine manufacturer with regard to functioning, operational reliability and service life.
2. Observance of all the statutory regulations such as safety factors, number of lifting chains to be fitted as well as all the relevant dimensional and fitting instructions.
3. Specific technical data.

Rexnord has a large number of data specific to chains which go far beyond the general catalogue information figures.

For every chain stipulation we recommend that use be made of our wealth of information and experience. We will gladly place at your disposal all of the data important for chain design such as fatigue strength, effective breaking strength values, link surface area as well as specific resistance to wear. Moreover, we are also pleased to be of service with special proposals for solutions such as with the design of lifting chains with plastic protection elements.

Explanations on the correct choice of chain

The calculation of the reliability of a chain taking the indirect route via the breaking strength and of a safety factor, depending on recommendation, of 5 or of some other factor, leads as a rule to undersizing. A chain is only correctly selected with 'certainty', if its fatigue strength is the same or larger than the tensile force and if the impact loads, as regards quantity and order of magnitude are in the fatigue strength in finite time range (see Chapter 3.5.1).

The fatigue strength, however, is in no way in a fixed mathematical ratio to the breaking strength. It depends decisively on the chain quality and on the plate combination of the leaf chains (see Chapter 2.3). Thus chains of the same breaking strength can, with regard to their fatigue strength, and thus in their true quality and also suitability, deviate from each other by up to 300 % from each other.

The safety factor error

The consequence of these facts would therefore have to be that for chains with different plate combination and manufacturer quality individually adapted safety factors would have to be chosen. If one really wants to carry this out in an appropriate way, safety factors from S = 5 to S = 31 are applied (see Chapter 3.5.2).

The choice of the correct safety factors in the last analysis becomes a safety risk

With the Rexnord load tables we offer you the possibility of achieving a pre-selection for your application.

As the performance ranges of the different leaf chains often overlap we recommend our technical advisory service to you for the final decision.

The Rexnord load tables for leaf chains are based on the following basic values:

1. Use of leaf chains of Rexnord quality.
2. Taking into account chain fatigue strength.
3. Taking into account the influence of the link surface pressure occurring.
4. Taking into account the influence of the plate combination.
5. Ensuring that all the impact loads occurring in usual use do not show any negative effects.
6. Fulfilling of what is known as the static safety factor of S min = 5.

3.2 Design for lifting devices

3.2.1 Statutory regulations

The static safety factor

The Official Gazette of the European Community demands for the use of leaf chains and roller chains in fork-lift trucks up to 10t carrying capacity a static safety of S = 5 min. This means that the breaking strength of the selected chain must be at least 5 times the value of the chain load. The chain load is determined from the nominal load and the weight of the moving mast part.

In the case of lifting devices with combined lifting equipment for lifting mast and driver's seat the use of two lifting chains of the same type is prescribed. The total breaking strength of the two chains must be at least 10 times the operating load (that means: nominal load + moving mast part including driver seat).

Deflection roller diameter

For industrial trucks a diameter of the deflection roller of at least 3 times the chain pitch is prescribed.

3.2.2 Admissible load values for the preselection of Rexnord leaf chains

For use in fork-lift trucks the BL series is best suited (see Chapter 1.3.1) and should be preferred for a new design.

Plate combi-nation	BL leaf chains Maximum admissible load in Newtons					
	2 x 3	3 x 4	4 x 4	4 x 6	6 x 6	8 x 8
BL 4	5,100	6,400	6,600	7,600	7,900	9,200
BL 5	7,100	9,000	9,100	12,500	12,900	16,000
BL 6	12,400	15,800	16,000	21,800	22,500	28,400
BL 8	18,300	23,400	23,700	32,200	33,300	41,600
BL 10	25,700	33,000	33,400	45,200	46,800	58,400
BL 12	34,700	44,100	44,600	60,900	63,000	75,600
BL 14	44,600	56,900	57,600	78,300	81,000	100,700
BL 16	62,700	79,000	80,000	110,200	114,000	140,000

For checking existing lifting devices or simply for comparison, however, the admissible load values of the AL series are listed.

Plate combi-nation	AL leaf chains Maximum admissible load in Newtons			
	2 x 2	4 x 4	6 x 6	8 x 8
AL 4	2,000	3,700	5,300	6,600
AL 5	3,400	6,400	9,000	11,300
AL 6	4,800	9,100	12,800	16,000
AL 8	8,700	16,200	22,800	28,300
AL 10	12,900	24,300	34,400	42,600
AL 12	17,700	33,300	46,800	58,400
AL 14	23,800	44,600	63,000	78,100
AL 16	30,600	57,600	80,900	100,500

These admissible load values are adjusted to use in fork-lift trucks. They meet all the legal requirements with a static safety of S = 5.

For the final laying-down we are pleased to offer you our advisory service.

In order to achieve good running characteristics and a uniform lifting movement we recommend, for fork-lift trucks, a deflection roller diameter of at least 4 to 4.5 times the chain pitch (see Chapter 1.2.4).

3.3 Design for machine tools and general mechanical and apparatus engineering

For the use as counterweight chains in machine tools and for use in general mechanical and apparatus engineering the F series is best suited.

As we recommend a special treatment of the chain link for counterweight chains in machine tools this use should be stated in inquiries and purchase orders under the key-word 'Machine tool chain' (see Chapter 1.3.2).

For use in general mechanical and apparatus engineering, as a rule, the standard type is sufficient (see Chapter 1.3.3).

For these applications we recommend deflection roller diameters from 5 to 7 times the chain pitch (particularly important for machine tools!).

Plate combi-nation	F leaf chains Maximum admissible load in Newtons			
	2 x 2	4 x 4	6 x 6	8 x 8
F 12	1,400	2,500	3,400	4,000
F 15	1,600	2,900	3,800	4,600
F 19	2,200	4,000	5,600	6,600
F 25	5,500	9,900	13,400	15,800
F 31	7,800	14,200	19,100	22,600
F 38	16,100	29,100	39,300	46,600
F 44	20,900	38,000	51,300	61,000
F 50	24,600	44,700	60,400	71,500
F 63	40,200	73,000	98,500	117,200
F 76	64,200	116,600	157,500	187,200

3.4 Examples from practice

Below you will find some examples which make clear the technical relationships with regard to practice.

Example from practice 1

A manufacturer in the field of apparatus engineering important for the chemical industry uses a number of fork-lift trucks of the same type which in each case are fitted with two leaf chains F 15-88, of a European make. This leaf chain has a predetermined breaking strength of F_B = 90,000 N. The link surface area A = 0.64 cm^2.

Each chain is - determined from the maximum nominal carrying capacity plus percentage weight of the moving mast part – loaded with F = 16,000 N. From this what is referred to as a static reliability of:

$$S_{stat} = \frac{F_B}{F} = \frac{90{,}000}{16{,}000} = 5.6$$

is calculated.

This design corresponds to the specifications of the safety authority. Here a minimum value of S = 5 is required.

The specific value resulting from load and link surface area for link surface area pressure amounts to:

$$p = \frac{F}{A} = \frac{16{,}000}{0.64} = 25{,}000\,N/cm^2$$

The main application purpose is the transport of boiler plates and boiler ends to the various production shops and to the final assembly shop. Here not only railway level crossings, but also partly minor potholes are driven over. The fork-lift trucks used do not have solid tyres but normal tyre equipment.

Results of use

Already after 500 to 800 operating hours fractures occur regularly in the moving plates of the leaf chain inner link and in the chain bolts.

Results of examination

The examination of the defective chains which came from a non-EU state in Europe yielded the following results:

Effective breaking strength: F_B = 97,600 N

Thus the actual so-called static safety factor is:

$$S_{stat} = \frac{F_B}{F} = \frac{97{,}600}{16{,}000} = 6.10$$

Quality of the individual parts

The plates partly show bore holes with insufficient quality, reflected in excessive edge break-off and scoring in the bore hole.

The force fits of the pins in the outer plates have excessively low values.

Evaluation of analysis

Although for this case of use the so-called effective static safety factor suggests complete operational reliability, after the shortest period of use both broken pins and also fractures in the moving inner plates occurred.

Broken pins

It was possible to clearly establish that all the broken pins have a common cause.

Already externally it could be seen that all the broken pins had turned through approx. 180 ° in the force fit of the outer plates.

They showed on the side away from the load marked scoring with considerable notch effect. From here the fatigue fractures (endurance failures) started. From this picture the following sequence can be easily and reliably reconstructed:

Theoretical damage analysis

As a result of the inadmissibly high specific surface pressure of theoretically 25,000 N/cm^2 in the case of the plate combination 8 x 8 the lubricating film in the chain link – between the pin and the plate bore hole – is repeatedly penetrated during the lifting movement. This led to what is known as mixed friction and to cold welding between the pin upper side (load side) and the moving plates.

With the given plate combination of 8 x 8 therefore up to 8 pins with cold welding are involved in twisting the pin in both force fits of the outer plates. This is a well known process. Once the pin has now turned through approx. 180 ° the original load side with its scoring comes into a position facing away from the load. At any load now following the notch-damaged surface is no longer in the pressure zone of the pin surface, but in the tensile zone. Fractures starting from the notches or scoring are the unavoidable consequence.

The occurrence of fatigue fractures (endurance failures) of this kind are in no way related to a breaking strength value or a so-called static safety factor.

This can be prevented only by the following measures:

a) Limitation of the specific link surface pressure

The specific link surface pressure must be restricted to a value which ensures that penetration through the lubricating film in the chain link under load during the movement of the link of the chain on the deflection wheel is prevented.

b) Limitation of the plate combination

It must be taken into account that the theoretical value determined by calculation for the actual link surface pressure of individual plates on a common pin provide only limited information.

The given tolerances in the plates as well as the bending of the pins occurring under load lead – depending on the load state – to a varying unevenness in the load distribution over the individual plates of an inner and/or outer link package.

Stress-extension test of lifting chains in fork-lift trucks

Rexnord has carried out stress-extension tests on lifting chains together with TÜV Rheinland (the complete TÜV report can be examined in our offices).

The evaluation of the elongation values in the individual plates with different load data and operating states yielded informative and extensive insights for new measures of quality improvement, such as high pre-stretching.

By means of elongation measuring strips on each individual plate, in the case of a leaf chain the elastic elongation under load and thus the stress in the plate concerned was determined.

In the case of the leaf chain with 1 " pitch and a plate combination 6 x 6 examined stress differences (max. value to min. value) of 2.4 times the value at maximum load and the greatest possible impact load occurred.
In the case of loading with the nominal carrying capacity without travel the stress difference was even greater. It had 4 times the value.

The lower stress difference at maximum load and maximum impact could be accounted for by the fact that the elasticity within the chain at rising load brings about a relative improvement in the load balancing.

Apparently these varying stress differences which became apparent in the test are attributable to the following facts:

1. Tolerances of the individual parts
2. Pin bending under load
3. Elastic elongation

If one now considers that in the case of the leaf chain F 15-88 used a theoretical link surface pressure with plate combination 8 x 8, of more than 15,000 N/cm^2 can already be critical it is soon seen that at a given value of 25,000 N/cm^2 increased by 2.4 to 4 times the value can trigger the premature pin fracture.

Influence of the plate combination

The greater the plate combination the more unfavourable does the ratio of plates moving on the pin to those which secure the pin against axial and radial torsion becomes.

1. Each leaf chain has, as a rule, only two outer plates with force fits!
2. The greater the plate combination, the more unfavourable does the load distribution in the chain become.
3. The greater the plate combination the lower is thus the relative fatigue strength.
4. The smaller the plate combination, the better is the leaf chain.

Leaf chain quality optimisation

The following measures optimise the uniformity of load distribution within a chain and thus the carrying capacity:

1. Choice of the smallest possible plate combination
2. Preference to largest possible pin diameter
3. Choice of lowest possible pin length
4. Use of the narrowest possible tolerances for plates and pins

Rexnord BL leaf chains here offer the optimum solution.

Quality optimisation by "high pre-stretching"

Moreover, series tests carried out by Rexnord have proved that high pre-stretching brings about a considerable improvement in the load distribution between the individual plates.

This method practised by Rexnord increases the fatigue strength of the chains quite considerably and thus increases the operational reliability.

Plate fractures in chain F 15-88

The cause of the failure involved in the plate fractures was also clarified beyond doubt. Fatigue fractures (= endurance failures) had occurred. Cause: the deficient bore hole quality and excessively high specific surface pressure, multiplied by the high non-uniformity of the load distribution in the plate combination 8 x 8. This then during operation brought about further scoring in the plate bore holes. These phenomena are responsible for the immediate defect caused by fatigue fracture.

Final conclusions from the analysis of the damage

On the basis of the description of the causes of the damage it has become clear that quite different factors than the breaking strength and/or a statistical safety factor determine whether a chain is operationally reliable.

The really important factors for the determination of the chain are:

1. The fatigue strength of the chain
2. The existing link surface pressure
3. The plate combination

Redesign of the lifting chains

In order to ensure reliable continuous operation without chain fracture the use of the BL leaf chain 823 was proposed and carried out. This chain has been running for years under the same conditions with absolute operational reliability. There are no longer any failures at all.

This chain has the following data:

1. Effective Rexnord breaking strength
   $F_B = 130{,}000\,N$
2. Rexnord fatigue strength
   $F_D = 28{,}000\,N$
3. Elastic limit of the Rexnord chain
   $F_E = 90{,}000\,N$
4. Existing chain surface area
   $A = 1.11\,cm^2$

From the above technical data of leaf chain BL 823 for a chain load of F = 16,000 N the following figures are obtained:

$$S_{stat} = \frac{F_B}{F} = \frac{130{,}000}{16{,}000} = 8.16$$

Safety from impact load

Existing safety from reaching the elastic limit at an impact factor of y = 2.8.

Remark

Rexnord field tests have shown that in the extreme case an impact factor of y = 2.8 can be expected.

Thus maximum impact value:

$$F_{st} = F \cdot y = 16{,}000 \cdot 2.8 = 44{,}800\,N$$

Thus safety from reaching the elastic limit:

$$S_E = \frac{F_E}{F \cdot y} = \frac{90{,}000}{44{,}800} = 2.0$$

Lubricating reliability and wearing life-span

Existing link surface pressure:

$$p = \frac{F}{A} = \frac{16{,}000}{1.11} = 14{,}414\,N/cm^2$$

On the basis of present experience this value states for the link surface pressure that with the use of a Rexnord leaf chain the problems encountered in example from practice do not occur and that an adequate wearing life-span is reached.

Operational reliability by means of adequate fatigue strength

Existing safety from endurance failures:

Dynamic safety:

$$S_{dyn} = \frac{F_D}{F} = \frac{28{,}000}{16{,}000} = 1.75$$

This value shows that full operational reliability is present over the entire wearing life-span of the chain.

Fatigue strength test of the failed leaf chain F 15-88

In the case of the fatigue strength test on the leaf chain F 15-88 which permanently failed after 500 to 800 operating hours a fatigue strength of 6,000 N was determined. Thus the originally fitted outside make leaf chain had only a dynamic safety of:

$$S_{dyn} = \frac{F_D}{F} = \frac{6{,}000}{16{,}000} = 0.38$$

As the fatigue strength characteristic curve (Wöhler curve) has an asymptotic pattern, this value shows that a failure of the chain at the given high stress must be expected after only a few operating hours.

Practice example 2

A steel works uses a large number of fork-lift trucks of the same type for the transport of coils. The equipment and also the leaf chains fitted are from a former country of the eastern bloc. Due to numerous premature chain failures after a few months of operation resulting from plate fractures an examination was carried out to determine the causes.

It was determined:

Technical data

1. Each item of equipment has two leaf chains of size BL 1234 with a DIN breaking strength of F_B = 226,800 N and a link surface area of A = 2.79 cm^2.
2. The load determined from the nominal load and the moving mast part for each chain was F = 25,000 N.

No significant impact load was present.

The lubrication of the chain was perfect.

The mathematical check on the chains used yielded the following results:

1. Existing effective static safety from fracture

Subsequently carried out breaking strength tests yielded an effective value of F_B = 253,000 N. This results in a so-called static safety factor of:

$$S_{stat} = \frac{F_{B\,eff}}{F} = \frac{253{,}000}{25{,}000} = 10.12$$

2. Existing link surface pressure

$$p = \frac{F}{A} = \frac{25{,}000}{2.79} = 8{,}960\,\text{N/cm}^2$$

On the basis of the data determined the premature chain damage cannot be explained since the static safety from fracture determined is more than 100 % larger than the one required according to the regulations. (Req. S = 5 min / Actual S = 10.12).

The link surface pressure is, with its low value, also roughly 80 % more favourable than the required value as for a BL leaf chain with plate combination 3 x 4 roughly 16,000 N/cm^2 is permissible.

As the determination of the load data showed that here a more than sufficient dimensioning as well as the choice of an optimum leaf chain – BL version with the good plate combination 3 x 4 – was present further tests were necessary.

The following faults were discovered:

Analysis of damage to outside-make chain BL 1234

1. Plate hardnesses

The hardness of the plates was much too high. The consequence is a drop in the fatigue strength with simultaneously increased breaking strength and enormously increased sensitivity to hydrogen embrittlement.

2. Poor quality of bore holes

A whole number of defects were found:

a. Scoring in the bore hole

b. Material overlapping in the bore hole

c. Inadequate percentage contact area of the bore hole, only approx. 40 %

d. Inadequate roundness of the bore hole

e. Deficient overlap between bore hole and pins in the outer plates, less than 30 % of the Rexnord value

All the above-mentioned defects lead, as is well known, to a considerable drop in the fatigue strength.

3. Inadequate heat treatment

In the link plates excessively large ferrite percentages were found in the micrographs. No adequate conversion to martensite had taken place: drop in fatigue strength.

4. Excessively sharp-edged marking in the outer plates

The resultant notch effect led even to the failure of outer plates. This is unusual despite the generally defective quality of all the plates: this also means a considerable additional drop in the fatigue strength.

5. Peripheral partial decarburisation

In the case of all chain plates a marked peripheral partial decarburisation (decarbonisation) can be found. Peripheral decarburisation or decarbonisation leads with certainty to fatigue fractures.

In order to establish the overall reduction of the fatigue strength and thus of the quality a number of fatigue strength tests were carried out with these chains. A value of F_D = 11,000 N was found.

Thus the real dynamic safety from chain fracture

$$S_{dyn} = \frac{F_D}{F} = \frac{11{,}000}{25{,}000} = 0.44$$

This value indicates that premature chain fracture (fatigue fracture) is programmed, although the so-called static safety factor is S_{stat} = 10.12 (Req. S_{stat} = 5 min).

The subsequent use of Rexnord chains of the same dimension yielded a full operational reliability and a very long wearing life-span.

In the case of the given Rexnord fatigue strength of F_D = 54,000 N for the BL 1234 leaf chain, a dynamic safety factor of:

$$S_{dyn} = \frac{F_D}{F} = \frac{54{,}000}{25{,}000} = 2.16$$

is obtained.

With reference to a required value of S_{dyn} = 1.0 min the value determined indicates that here full operational reliability exists for the whole wearing life-span. Fatigue fractures and also overload fractures are thus excluded.

Summarised evaluation of the results of the tests from the two examples from practice 1 and 2

On example from practice 1

Although the static safety factor determined shows a value of $S_{stat} = 6.1$, a completely inadequate operational reliability was obtained.

The causes are:

1. Selection of a chain with excessively large plate combination.
2. Excessively high effective link surface pressure which in combination with the unfavourable load distribution brought about by the high plate combination led to link pitting with pin fractures as the consequence.
3. ***Medium*** quality of the chain F 15-88

*The **medium** quality and the high plate combination of the originally used chain F 15-88 would have required a considerably higher so-called static safety factor, namely S min = 16 (see following calculation).*

Selection of chain

If one were to select a leaf chain of the same ***medium*** quality and plate combination 8 x 8 which is to ensure absolutely reliable operation this must show a required value for the dynamic safety factor of $S_{dyn} = 1$ (min).

According to the following proportion determined from this is the following required value for the so-called static safety factor:

$$S_{stat\ act.} : S_{stat\ req.} = S_{dyn\ act.} : S_{dyn\ req.}$$

$$S_{stat\ req.} = \frac{S_{stat\ act.} \cdot S_{dyn\ req.}}{S_{dyn\ act.}}$$

$$S_{stat\ req.} = \frac{6.1 \cdot 1}{0.38} = 16.0$$

From this it can be seen that a leaf chain with at least the following breaking strength must be used:

$$F_{B\ req.} = F \cdot S_{stat\ req.}$$

$$F_{B\ req.} = 16{,}000 \cdot 16 = 256{,}000\,N$$

According to the Rexnord “Actual breaking strength $F_{B\ req.}$” (ask our application advisory service department for the effective Rexnord breaking strength) for this the chain F 25-88 with an effective breaking strength of $F_B = 320{,}000$ N can be considered.

This means that for the offsetting of the ***medium*** quality a leaf chain must be selected which shows the following deviations:

1. Breaking strength:	+	328 %
2. Overall height:	+	60 %
3. Weigth:	+	174 %
4. Price	+ approx.	150 %

Thus the conclusion is permitted that the use of chains of ***medium*** quality is technically irresponsible and cannot be justified commercially.

The chains BL 823 used by Rexnord were absolutely operationally reliable. Moreover, an improvement of the range of vision for the driver was obtained since the BL 823 chain has a smaller overall height.

An example from practice 2

The outside-make chain BL 1234 originally used here has an outstanding value for the so-called static safety. It amounts to S_{stat} = 10.12. The link surface pressure is also extraordinarily favourable. Moreover, the fact that here a BL leaf chain with the small load combination 3 x 4 was selected must be seen as optimum.

Although the selected chain theoretically in principle offered the best prerequisites, the results in use – despite the favourable load data – were extraordinarily poor. The cause of the poor results is counted for exclusively by the defective quality. The ***defective*** quality of the outside make of chain is expressed in the extremely low fatigue strength of only 11,000 N. The Rexnord value is 54,000 N. Thus the Rexnord quality is roughly 5 times better.

On the basis of the ***defective*** *quality of the make used here in particular a chain with a so-called static safety factor of* $S_{stat} = 23$ *would have been sufficient. (See the following calculation and table on page 43).*

By analogy to the selection of chain from example 1 here a required value for the so-called static safety factor of:

$$S_{stat\ req.} = \frac{S_{stat\ act.} \cdot S_{dyn\ req.}}{S_{dyn\ act.}}$$

$$S_{stat\ req.} = \frac{10.12 \cdot 1}{0.44} = 23.0$$

Selection of chain

If one would here to use a chain with the same plate combination 3 x 4 and the same ***defective*** quality which is to offer a full operational reliability this requires a breaking strength value of at least:

$$F_{B\ req.} = F \cdot S_{stat\ req.}$$

$$F_{B\ req.} = 25{,}000 \cdot 23$$

$$F_{B\ req.} = 575{,}000\,\text{N}$$

The 'Rexnord actual breaking strength table' (for Rexnord actual breaking strengths please ask the application advice department of Rexnord) indicates for the leaf chain BL 1634 an effective breaking strength value of F_B = 650,000 N. This chain would therefore be adequate.

If one takes into account that a leaf chain BL 1234 of good quality already offers an absolute operational reliability and also a long wearing life-span, for the use of a BL leaf chain 1634 of ***defective*** quality the following differences are to be noted:

1. Breaking strength:	+	175 %
2. Overall height:	+	39 %
3. Weigth:	+	56 %
4. Price	+ approx.	60 %

Here, too it can be seen that the use of chains of ***deficient*** quality result exclusively in disadvantages from both the technical and commercial points of view.

3.5 Results of the examinations of the examples from practice

3.5.1 The elastic limit in relation to impact load

The impact load must not exceed the elastic limit. Empirical studies concerning fork-lift trucks have shown that if the chain is designed according to Rexnord criteria – even at the toughest stress – the impact load always remains below the elastic limit. Experience shows that the whole impact load complex is sufficiently low to exclude endurance failures during the whole of the wearing life-span. The impact load occurring in the fatigue strength in finite time range is also uncritical. The maximum value is $y = 2.8$.

3.5.2 Safety determination

By means of static safety factors it would be essential to take into account the influence of chain quality and plate combination on the fatigue strength, as can be seen from Chapter 3.4.

Due to the results of fatigue strength examination series as well as the evaluation of cases of damage, the following so-called static safety factors would that have to be applied:

Plate combination	Factor to be chosen (min) for the so-called static safety "S"		
	good quality	medium quality	defective quality
2 x 2 and 2 x 3	5	7.5	15
3 x 4 and 4 x 4	7	11	23 *
4 x 6 and 6 x 6	8.5	13	25
8 x 8	10.5	16 *	31

* see Chapter 3.4 "Examples from practice"

The higher static safety factors required in the case of medium and/or defective quality as well as in rising plate combination exactly reflect the fatigue strength drop as compared with chains of good quality.

4.1 Lubrication

Rexnord chains are given preference in use by many important manufacturers of lifting devices, machine tools and storage and retrieval units for high-bay warehouses and in general mechanical engineering because of the above-mentioned safety and quality features as well as of the long service life.

In order to make these characteristics also take effect in the hands of the customer, conscientious maintenance and lubrication is necessary.

4.1.1 Re-lubrication intervals

The necessary re-lubrication intervals depend on the particular use and the ambient conditions and must be granted in such a way that there is always sufficient low-viscosity oil present in the chain link.

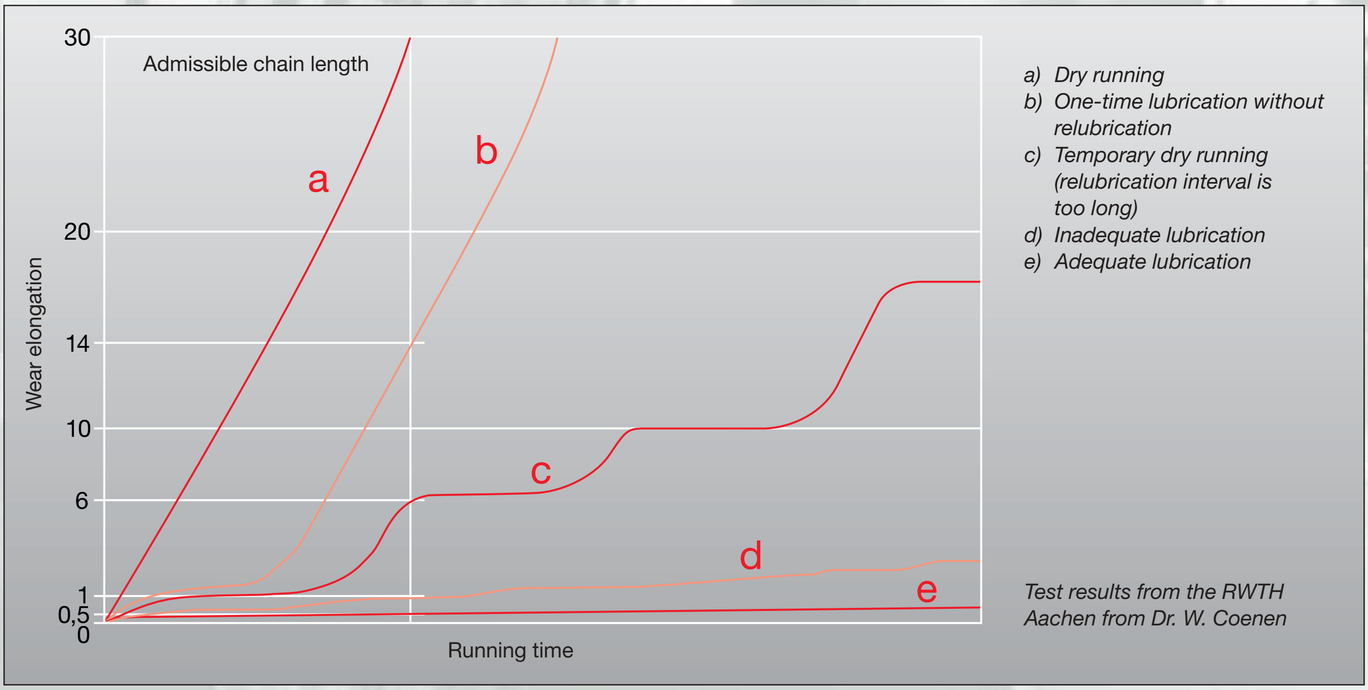
For use in stacker trucks, re-lubrication should be carried out, for example, ***every 250 operating hours;*** in the case of severe fouling, the effects of moisture and very high permanent load as early as ***after 100 operating hours.***

If corrosive fluids are acting on the chain the chain should be immediately cleaned and lubricated.

Fork-lift truck at work.

4.1.2 Lubrication

As the following diagram shows, the service life of an adequately lubricated chain is 60 times longer than in the case of dry running.



Elongation through wear as a function of lubrication and operating time.

Incorrect lubrication

Approximately 60 % of all the chain defects are attributable to incorrect lubrication. Thus with allegedly good carrying-out of lubrication, friction corrosion, twisted pins, metal friction, stiff links and noise production and pitting formation are obtained.

This is always the case, if the lubricating product applied adheres only externally but has not penetrated as far as the chain links.

This phenomenon occurs when non-free-flowing products are used for lubrication.

Lubricating products with thinners

Lubricating products of this kind are offered predominantly in spray cans. The advertising arguments of these spray can manufacturers is as follows:

"The lubricating product, still liquid as a result of the thinner, penetrates into the chain link. The thinner evaporates. Then a tenaciously adhering, firm lubricating film remains behind. This ensures optimum lubrication."

Experience teaches us that this, as a rule, is a total illusion.

On the part of the chain manufacturers, the chains are provided for a large number of well considered reasons, with a corrosion protection and lubricating grease ex-works. This is applied and introduced in a hot bath.

If these chains are now put to use, a certain deposit of dust on the chain surface can additionally be expected. This stiffens the existing outer grease layer additionally.

Pitting on pin and plate.

If a lubricating agent which is stiff as regards the basic viscosity, which is kept liquid temporarily only by means of a thinner, is now sprayed onto the chain, the following occurs:

The outer grease layer already present is dissolved to some extent on the outside. For this the thinner has already been used up. No new lubricant penetrates into the chain link.

Merely the outer grease layer builds up further and now absorbs light fouling more easily.

The applier of these lubricating products is promised an optimum chain lubrication by the suppliers of these spray cans. The grease adhering in great thickness on the outside also suggests good lubrication. Unfortunately the opposite is the case

Condensation rust

If chains are externally covered with a stiff layer of grease homogeneously, in the links – due to the link movements – the formation of cavities can partially occur. New lubricant cannot follow as it is not sufficiently free-flowing and the newly applied lubricant leads only to additional stiffening.

If such lubricated chains are subjected to marked temperature changes the formation of water of condensation comes about in the chain links. Here, in particular, the chains which, during the day, are exposed to direct solar irradiation and cool down markedly afterwards (at night), but also such chains as work inside and alternately outside of cold storage houses are affected. The consequence is link corrosion which in turn leads to stiff chain links. In particular new chains which still have a very low link tolerance, have a tendency to rust in.

Further consequences are pitting in the link parts.

These, in turn, trigger premature fatigue fractures.

For the owner or user, damage based on this circumstance, it is rather difficult to understand as the lubricant manufacturers promise optimum results and the chain, in addition, creates a well lubricated impression from the outside.

Particularly for this reason, a warning about these products is necessary.

Correct chain lubrication

Leaf chains are correctly lubricated and are in a perfect condition if:

1. No external dirt is adhering.
2. When the chain is touched the finger is moistened with oil.

Then it is also certain that the lubrication of the chain links is adequate.

Remark:
For the maintenance of the chains with lubricating oil it is in no way necessary to apply such quantities that the oil drips from them.

The correct chain preservation

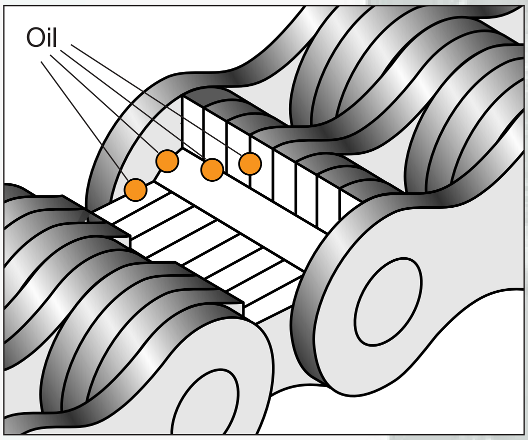
With the correct chain lubrication, the preservation is also automatically satisfactory.
This means that corrosion and pitting are excluded.

Criteria of correct choice of lubricant and its application

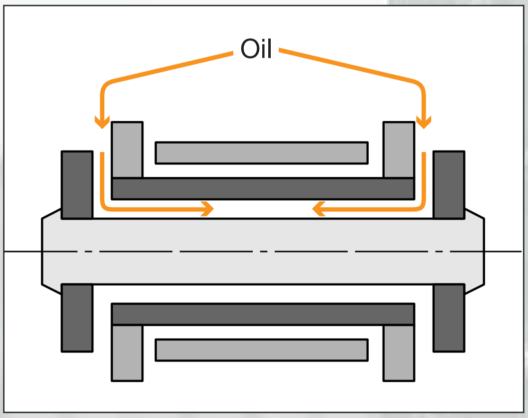
In order to achieve effective lubrication in each lubricating process, an adequate quantity of a liquid lubricating product is introduced into the chain links.

Rexnord-high-performance chain spray.

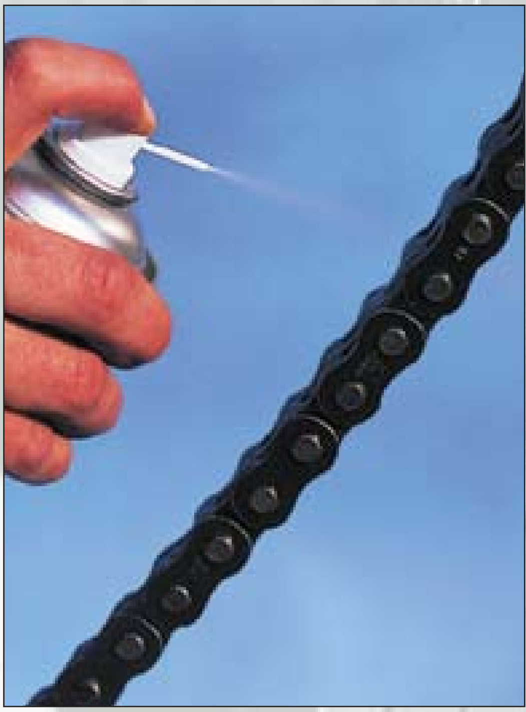
Cut-away chain.



Chain cross-section.



Lubricating with spray can.



The sectional drawings of the chain links in the case of roller chains and leaf chains clearly show that lubricating product must move forward a long way between narrow plate gaps in order to reach its most important goal, the chain link.

The further task of the lubricating oil is to ensure an adequate protection from corrosion. This is achieved by moistening of the surfaces with an adequate film thickness.

Devices with lifting chains which are exposed outdoors to all weather conditions naturally require a slightly higher expenditure on servicing.

Type of lubricant

A low-viscosity mineral, machine or also motor oil and/or synthetic oil should always be used.

Viscosity

The viscosity of the lubricating oil is to be selected in such a way that at all ambient temperatures occurring it remains low-viscosity. Under the usual, normal temperature conditions lubricating oils with a viscosity of SAE 20 to SAE 40 (50 to 200 mm^2/s at 40 °Centigrade) can be considered.

Use of spray cans

If one wishes to lubricate the chains by using spray cans it must be ensured that hereto the basic demand is met which states: After the evaporation of the thinner a viscosity must be achieved which corresponds to the above-mentioned recommendation.

The Rexnord high-performance chain spray reliably meets the demands which can be made on a lifting chain lubricant.

Lubricating methods

The lubricating product can be applied by means of a brush, a paintbrush or with compressed air spray devices.

4.2 Inspection

Chains have, in comparison with many other traction means, the advantage that damage or the reaching of the wearing life-span announces itself by signs in advance.

4.2.1 Inspection intervals

In order to identify these advance signs early, we recommend regular inspections be carried out.

For use in stacker trucks, there should, for example, be an inspection at least annually. In the case of marked fouling and very high permanent load, every three months.

4.2.2 Test features

We recommend observing the following points:

1. Noise production

In the case of dry friction in the chain links, shrill squeaking or deep grating noises can occur in the chain links. They occur exclusively as a result of a shortage of lubricant in the chain links. During the link movement in inward and outward travel round the deflection wheel metallic friction takes place.
This is then the cause of the noise production and possibly also leads to slip-stick effects. This sliding-back in the chain link leads to a disharmonious movement behaviour.

2. Surface rust

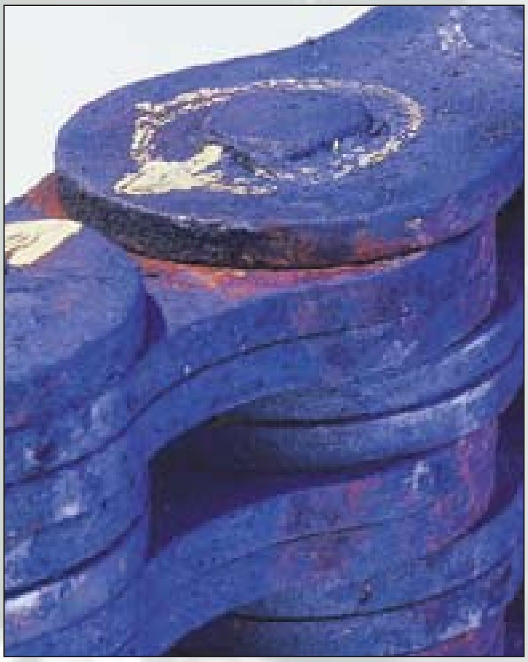
Surface rust can be recognized easily by the brown colouring of the plates. Unfortunately this external appearance is not only a visual matter. What is dangerous is the pitting always related to this.

Pits are small craters. They form in all parts of the chain if there is a shortage of, or wrong lubrication. Pits are starting points for premature fatigue fractures.

3. Link rust

Friction corrosion leads to the reddish-brown colouring of the link zones. Link rust is also

Surface rust.



Link rust.

Stiff links.

Twisted pins.

Loose link pins.

Inadmissible external wear.

referred to as "bleeding" of the chain. It can occur due to generally deficient lubrication. Moreover, if greases of thickening oils which do not penetrate into the chain link are used. Such products are unsuitable for the lubrication of lifting chains.

4. Stiff links

If the chain links do not go back into the stretched length after leaving the chain deflection wheel, the chain link is no longer functionally efficient. This phenomenon can be caused by cold welding, link corrosion or briquetting.

5. Twisted pins

Twisted pins are a further indication of a defective chain lubrication and are considered a phenomenon arising as a consequence of stiff links. In this case the blocking of the links is already so strong that the force fits between link pins and outer plates have been overcome.

Twisted pins are easy to recognise. Their rivet flattening on the front ends deviates from the factory arrangement.

6. Loose link pins

Chains which show loosened pins in the force fit of the outer plates represent a direct danger for the rupturing of the chain.

Pins loosened in the force fit of the outer plates are a direct consequence of "stiff links" and "twisted pins".

7. Inadmissible external wear

It is to be examined whether the plates of the chain show outer wear, e. g. due to continuous rubbing on mast parts or in the contact area of the deflection rollers.

The wear must not exceed 5 % of the original plate cross-section.

8. Damage

Do the chain plates show impact markings or other deformation?

9. Broken plates

Broken chain plates are indicated by "locking" of the plate concerned in the area of the plate head or by the absence of the head part.

Here we are dealing with fatigue fractures (= endurance failures) due to an overload.

Corrosion can also be the initiator of such fractures.

10. Broken pins

They occur as a rule mainly as a consequence of corrosion in the chain link.
This corrosion leads to pitting on the pins.
It, in turn, is then the starting point for fatigue fractures (endurance failures).

It is part of the peculiarity of this phenomenon that in such cases several broken pins can occur in a short time sequence, since all the plate pins are subject to the same conditions regarding corrosion, load and impact absorption and therefore – a reduction in fatigue strength – mainly due to corrosion. Thus it is natural that when dismantling such a chain often several broken pins are found.

Practice shows that such fractures are not always easy to recognize since in the initial stage no marked change in the chain pattern appears.

A careful inspection is therefore necessary. Such an inspection is, however, very difficult if the chain is covered in a thick layer of grease. Without thorough cleaning beforehand a reliable result cannot be achieved.

Damage.

Broken plates.

Broken pins.

Fouling.

Wear in the hole.

Wear on the chain pin.

11. Fouling

Chains which are fouled to such an extent that the oil applied for lubrication cannot penetrate directly to the chain link do not experience any reliable lubrication.

Also, applied grease effectively prevents the access of oil to the links

12. Chain elongation

Even with optimum lubrication, in the course of the years a chain elongation cannot be avoided. It is caused exclusively by wear in the chain links. The wear merely applies to the area of the chain which is led over the sprocket/deflection wheel. Thus, for the measuring of wear, this area is the only one to be looked at.

An inclusion of other chain sections would falsify the result.

According to the currently applicable regulations a chain is considered worn when it has been lengthened by 3 % (i. e. 30 mm per 1 metre).

In the United Kingdom and some other countries many companies and service centres have reduced the admissible wear limit to 2 %.

If safety interests are very decisive or if possible endangering depends on a single chain, we consider replacement to be necessary already at 2 % elongation.

For a new design we recommend the use of two chains for safety reasons.

Measuring process

For measuring the wear elongation, the part of the chain which runs over the sprocket/deflection wheel is moved into the stretched area. With the help of a measuring rod an approximately 1 metre long piece is then measured. Advisably, measuring is carried out from one pin lower edge to another pin lower edge. The number of pitches in the measured area, multiplied by the chain pitch, gives the nominal dimension. The length exceeding this dimension represents the wear which is limited with a maximum of 3 % to the nominal length.

If a new chain is present, a 3 % wear elongation can also be determined by a comparison. A 3 % wear elongation is achieved if the chain in operation with 33 links has reached a length with which it corresponds to 34 links of a new chain.

Should in the case of the above-mentioned measuring processes it become clear that within the selected measuring section sections of different wear elongation are found, a second measurement is to be carried out.

The second measurement should only cover the section of the maximum elongation. Also in this section the length increase should not exceed 3 %.

Also with the help of the Rexnord wear ruler the wear elongation can be determined. This measuring instrument is available to our customers on request.

Effective pitch

While in the case of the BL leaf chains the nominal pitch and the effective pitch match, in the “AL” (light American series) and “F” (European series) versions there are deviations.

Exact recording of measurements is only possible when the effective pitches are taken into account.

The exact pitching dimensions can be taken from the Rexnord catalogue “Quality chains”.

Measuring elongation.

Hydrogen embrittlement.

13. Hydrogen embrittlement

If hardened (fully hardened) materials are exposed to free hydrogen (chemical symbol H) the material readily absorbs this substance from the surroundings.

This absorption leads to the destruction of the molecular bond in the hardened steel. All chains and anti-friction bearings are affected by this phenomenon.

So far it may have surprised many a user of chains that without overload in the case of chain plates, a deformation-free embrittlement fracture has occurred. If, however, free hydrogen is available in the atmosphere, such fractures are unavoidable.

As a rule only the outer plates are affected by this phenomenon since due to the high force fit between the plate pins and the outer plate tension built up in the plate is sufficient to produce embrittlement fractures with the influence of hydrogen. A load on the chain by means of a tensile force is not necessary for this.

Free hydrogen arises, for example, in the following cases:

1. Contact between metals and acids, e. g. $H_2SO_4 + Fe = FeSO_4 + 2\,H$
2. In every electrolysis.

For the above-mentioned reason cadmium plating, chrome plating and galvanising of chains already fitted in the possession of the customer by electrolytic means entails lots of risks.

The cleaning of the chains with aggressive agents, e. g. boiling of the chains in P3, or the use of cleansers containing chlorine can immediately produce embrittlement fractures.

Cold cleaning and steam blasting of the chains can lead to the same phenomena.

4.3 Cleaning

The correct chain cleaning

If during operation the chain is fouled externally to such an extent that the penetration of the lubrication oil is no longer ensured, chain cleaning must be carried out.
This must be carried out only with paraffin derivatives such as diesel fuel, petroleum, cleaning petrol etc.

Cleaning with steam blasters, the use of cold cleaners or even caustic and acidic agents must be warned against. They can lead directly to chain damage.

Chain cleaning by means of steam jet devices

In certain cases of use, e. g. in artificial fertiliser plants, during bagging of cement and other dusty products at short intervals considerable fouling of the lifting chains can occur. If for such uses, recourse is taken to cleaning by means of steam jet devices, this should take part exclusively without the use of aggressive, caustic or chlorine-containing cleansers. Clear water and / or steam is the least harmful aid.

It is easily understandable that after such cleaning of the chain it is not only cleaned but totally degreased. It is in this condition – particularly also due to the presence of water – exposed to rapid and dangerous corrosion.

Particularly in the chain link, i. e. between the contact faces of the plate bore hole and the pin surface the water film is retained longest and then triggers corrosion and pitting.

All the tests so far carried out by us with regard to the causes of failure in lifting chains shows that such corrosion is the main cause of premature chain damage. Mainly the plate pin is endangered here.

Optimisation of the cleaning method using steam jet devices

If such a cleaning method cannot be avoided we recommend the following procedure:

1. Cleaning

Cleaning of the chain by means of steam or hot water without the use of any additives.

2. Blowing-off

Immediately after cleaning, the chain is to be freed with compressed air from the water present on the surface and in the chain links.

For this procedure the chain is to be moved several times.

3. Spraying

Then the chain is to be immediately sprayed with a preserving and lubricating agent. Also for this procedure the chain is to be moved sufficiently often so that the product used can also actually penetrate through to the chain link.

4. Products to be used

Only products are to be used here which show the following characteristics:

- sufficient creepability
- sufficient corrosion protection and lubricity
- ability to move under water
- also after the application permanently free flowing
- good adhesivity
- build-up of a protective film with sufficient film thickness in order to withstand later mechanical attack (driving rain, hail).

In order to meet these various requirements, Rexnord has developed a high-performance chain spray for lifting chains which has been optimised specially for this task.

4.4 Replacement of the chain

If a chain replacement becomes necessary due to the wear elongation occurring or due to one of the above-mentioned faults or cases of damage, it is responsible to use a quality product which meets all the demands which can be made on a safety element.

If in the case of the device concerned, two chains are used as a pair, both should always be replaced at the same time.

Original Rexnord chains for replacement offer the same high quality and operational reliability as in the first equipment.

Assembly and disassembly of the chains should be carried out with the care required for a safety element.

The following rules should be observed:

1. Use only original Rexnord parts.
2. Rivet heads are to be ground down before the driving-out of the pin so that the moving inner plates are not damaged in their bore holes.
3. During repair only new outer plates and new pins may be used since the fatigue strength and thus the operational reliability depends decisively on the use of plates with score-free bore holes and an adequate force fit.
4. For a chain replacement in any case, the connecting pins between the chain anchor and the chain should be replaced. They are exposed to high impact loading.
   By means of this preventive replacement – in relationship to the new chain – premature fatigue fracture is prevented.
5. For repairs, riveting by hand by means of a hammer is sometimes unavoidable.
   It must be understood for safety reasons, that it is necessary to proceed with great caution in this situation.

First of all it is necessary to wear protective goggles for this since partial splintering from the pin head cannot be excluded.

It is to be ensured that no damage to the outer plates is caused since, as a result of this, fatigue fractures can be brought about.

During riveting, only a medium deformation of the pin head is necessary, since the main securing of the pin in the outer plate against lateral migration and twisting must be achieved by the force fit.

During fitting as well as during riveting of the pin, it must be ensured that on the one hand adequate play is present between the plates in order to ensure the movability of the links, and on the other hand the pin projection must be sufficient in order to achieve a rivet head in line with regulations.

We do not recommend the extending of safety lifting chains because the repair chain link inserted is not pre-stretched.

If during repairs chain sections of different silver label numbers are combined, the manufacturer's liability is extinguished.

Installation note

For the fitting of new chains or for the overhauling of devices, the chains should in no way be painted. This simply prevents the chain link from being effectively lubricated. Painted chains prevent the penetration of lubricating oil.

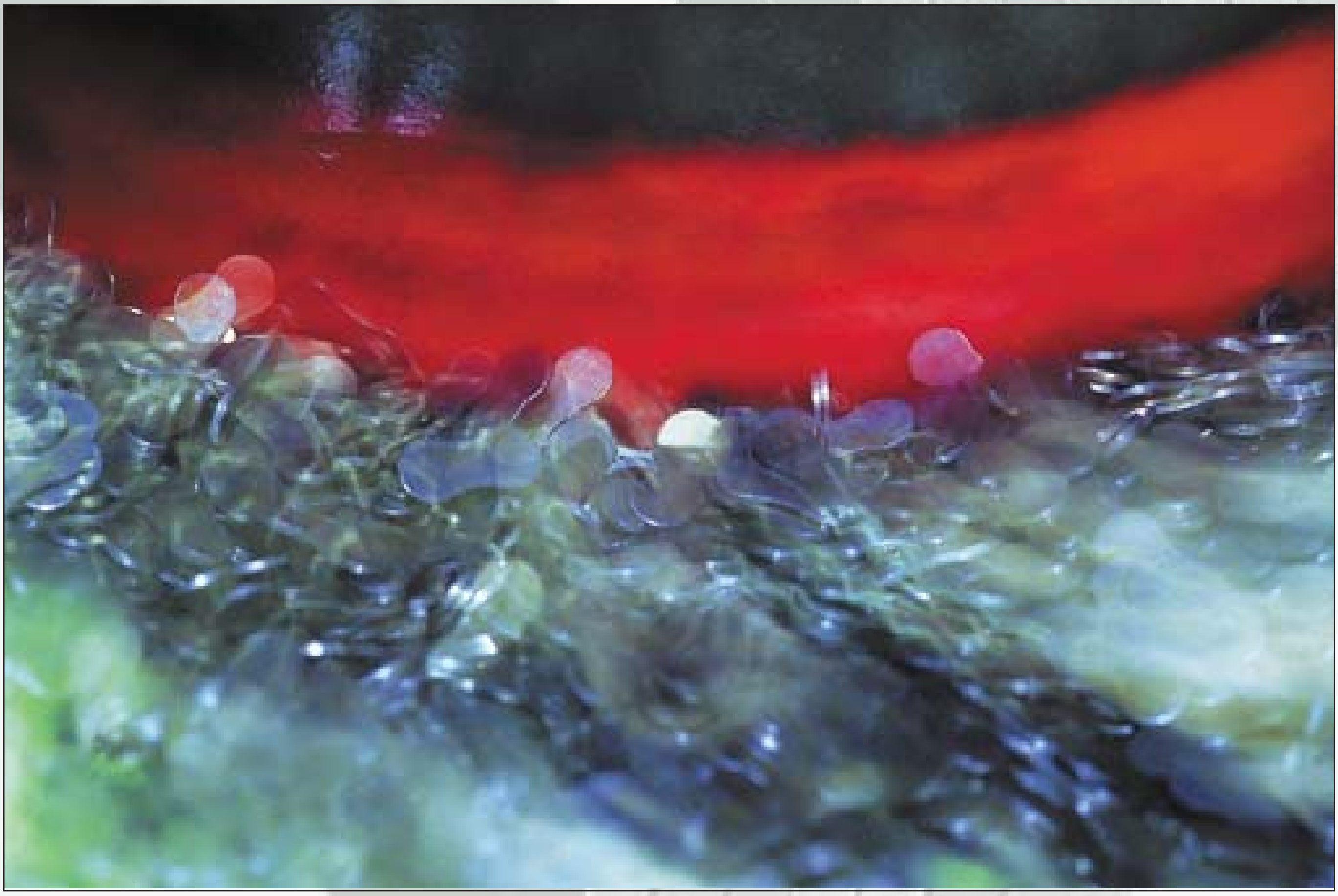
4.5 Summary

Lifting chains are safety elements. They are produced with great expenditure.

Whether they prove successful in the hands of the customer depends, however, to a considerable extent on proper maintenance and lubrication.

The diagram in Chapter 4.1.2 shows:

It depends on the maintenance behaviour of the user, whether one can achieve a 60-fold, 12-fold or inadequate service life.



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