

WEAR OF CONVEYOR CHAINS WITH POLYMER ROLLERS

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Abstract Roller conveyor chains are common used to transport goods in production lines or assembly lines, such as pallets, cars or steel coils. They are sometimes used in severe environments, soiled with water, foreign particles, chemicals or other contaminants. Normal use will result in wear of the components of the chain which can lead to unexpected failure and costly production downtime. Today, few literature on the wear of conveyor chain is available and there are almost no reliable test-rigs to generate and measure chain wear in a reproducible manner. In this research the different components of conveyor chains and the loading conditions are described. Additionally, the applications and (dis)advantages of chains with polymer rollers are discussed. The chain wear mechanisms found in literature are listed. Abrasive and adhesive wear between pin, bushing, roller and track are discussed. From the contact mechanics of the chain and pressure-velocity limit of the roller materials, the design constraints for the laboratory test-rig were derived. The capabilities and working principles of the developed test-rig are explained in this paper.

Keywords wear, conveyor chain, polymer rollers, test rig design

1 INTRODUCTION

Roller conveyor chains are generally used in production or assembly lines where individual large objects need to be conveyed. Typical applications of roller conveyors are carrier conveyors for the transport of steel coils in a steel plant or slat conveyors that carry objects. A slat conveyor consists of two or more endless strands of chain with attached non interlocking slats or metal flights to carry the material. Other examples are conveying pallets, tree-stumps or even whole cars. Wheeled cars, for example, can be carried by the chain but can also be pulled by the chain. Applications can be divided in two basic conveying modes [1]:

- The material is supported and carried entirely by the chain and attachments.
- The chain does not support the material, but it is pushed, pulled or scraped.

Roller conveyor chains differ from transmission roller chains such as a bicycle chain, which is used to transfer torque instead of conveying goods. Conveyor chains have a large pitch which is efficient in bridging large distances with fewer shackles, they generally have thicker side plates and rollers with large diameter. Therefore they can withstand higher tensile and shock loads than transmission chains. Furthermore they can bear large amounts of wear before breakage occurs. On the other hand, roller conveyor chains have a necessary clearance that easily becomes contaminated with particles from the conveyed material.

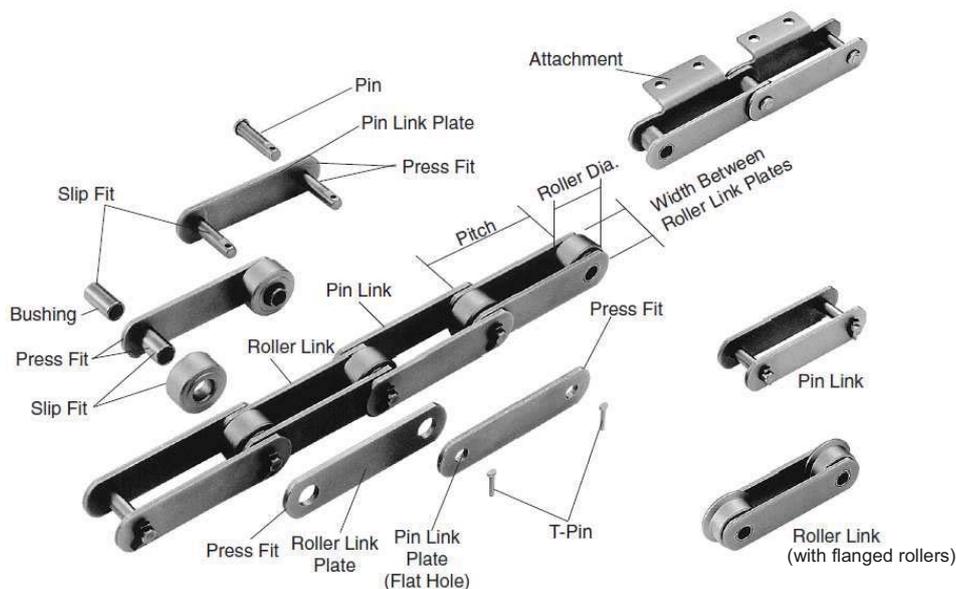


Figure 1: Basic structure of a conveyor chain [2]

A typical conveyor chain is constructed with two different types of shackles: the roller link (or inner link) and the pin link (or outer link), see Figure 1. The roller link consists of two steel bushings who are press-fitted inside the roller link plates, while the pin link consists out of two steel pins press-fitted inside the pin link plates. To prevent disengaging of plates and pins, riveted pins or t-pins (as shown) are used.

Conveyor chains can be loaded in two ways: the force can be applied on the side plates by use of attachments which are connected to the side plates, see Figure 1. Alternately the force can be applied on the pins. Therefore hollow pins and axles instead of solid pins (as shown) are used. The rollers transfer the normal force, due to the weight of the conveyed objects, to the track. The driving sprocket, exerts a force on the chain to pull the load, this results in a tensile force inside the chain which must be large enough to overcome the sliding friction between roller/bushing and the rolling friction between roller/track. Additionally the chain is prestressed by the sprockets, this will result in a raise of tensile force. To transfer this tensile force from one shackle to another, bushing and pin will act together as a bearing. The mechanics of these contacts are further discussed in section 2.1.

The use of chains with polymer rollers is gaining importance. In a water treatment plant, for example, lubrication is unwanted for environmental reasons. Other applications can be found in food industry and pharmaceutical industry, where contamination of the product with oil of the chain is unwanted. Chains with polymer rollers are capable of working without any lubrication, have good corrosion resistance, run quieter and weigh less than chains with steel rollers. The disadvantages of polymer rollers in comparison with steel rollers are: the lower heat resistance due to softening or even melting of the polymer, the lower yield strength and the water absorption of the polymer [1, 2]. Polymer rollers are often placed on a stainless steel chain, for example austenitic RVS 304, to obtain a chain that is entirely corrosion resistant. Different polymer materials are frequently used for the rollers: PA6/6, POM-C, POM-H, PEEK and patented polymers especially developed for chain manufacturers. For example IGUS Iglidur by Renold Chain [3, 4] or VRP(U)-series by Tsubaki [5]. To compare the suitability of different polymers, the pressure velocity limits (Pv-limits) are shown in Figure 2 using a logarithmic scale. Notice that PEEK rollers can withstand the highest contact pressures and sliding speeds. On the other hand, PEEK is more expensive than POM or PA rollers and has a higher friction coefficient and specific wear rate than POM or PA, see Figure 3.

Few literature on the wear of polymer roller conveyor chain is available, this research will study the wear behaviour of chains with polymer rollers. There are almost no reliable test-rigs available to generate and measure chain wear in a reproducible manner. Therefore a test-rig was designed, the required capabilities of this set-up are discussed in section 2.3.

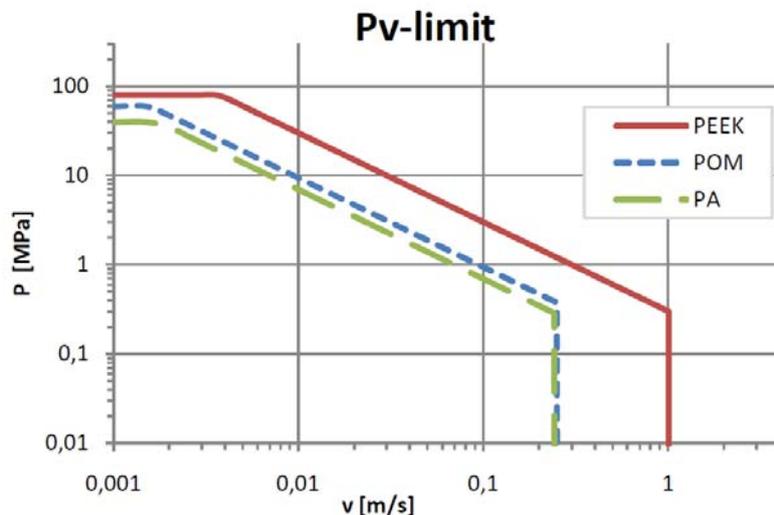


Figure 2: Pv-limit diagram of common polymers [6-10]

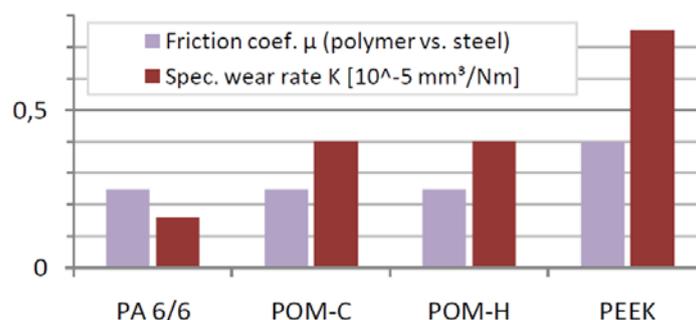


Figure 3: Friction coefficient & specific wear rate of different polymers [6-9]

2 STUDY OF CONVEYOR CHAINS WITH POLYMER ROLLERS

2.1 Contact mechanics

2.1.1 Overview of forces acting in conveyor roller chains

In this section, the contact mechanics are studied of a conveyor roller chain that transports pallets which are carried entirely by the chain. The chain is rolling over a track from left to right, see Figure 4. The weight of the pallets is applied on the pins of the chain, resulting in a normal force N_{02} on each pin. A tensile force F_t is exerted on the chain by the sprockets. This tensile force F_t will be transferred from the inner link to the outer link by bushing and pin acting together as a bearing. The normal force N_{02} is transferred from pin to bushing and then from bushing to track through roller. Notice that pin and bushing have a small clearance resulting in eccentricity e_{23} . Analogous, bushing and roller have a small eccentricity e_{34} (exaggerated on drawing).

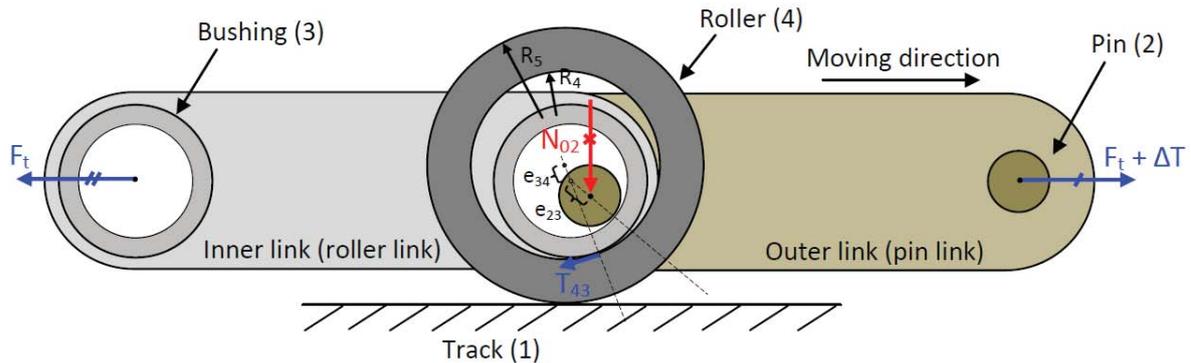


Figure 4: Section view of a roller conveyor chain with exaggerated clearances

The sliding contact between roller and bushing is discussed in section 2.1.2, while the rolling contact between roller and track is discussed in 2.1.3.

2.1.2 Sliding contact between bushing and roller

To calculate the maximum load for this conform bushing/roller contact, we can assume that the contact zone will be a line with finite width. This is called a Hertzian line contact. The pressure distribution is half-elliptic. The maximum Hertzian pressure p_{max} is indicated on Figure 5. Notice that it is higher than the mean contact pressure p_{mean} .

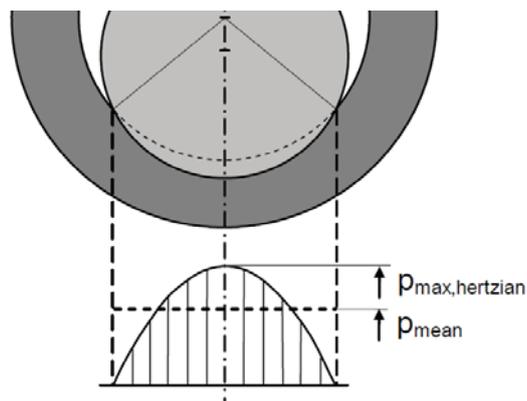


Figure 5: Hertzian pressure distribution in roller/bushing contact [10].

The contact between roller and bushing is a pure sliding contact. As the roller slides over the bush, a tangential force T_{43} appears on the bushing. It engages tangential to the bushing and roller and opposes the movement of the chain. The force T_{34} ($=-T_{43}$) acts on the bushing but is not shown in Figure 4. The friction coefficient μ_{slide} applies at the bushing/roller contact face and needs to be scaled with their diameters to obtain the equivalent coefficient of friction for the bushing/roller contact. This is calculated in equation 1 [1, 11]. Notice that when assuming rollers with the same inner radius R_4 , the rollers with a larger outer radius R_5 have a mechanic advantage on rollers with a smaller outer radius because their resulting equivalent coefficient of friction $\mu_{slide,equiv}$ will be lower.

$$\mu_{slide,equiv.} = \mu_{slide} \cdot \frac{R_4}{R_5} \quad (1)$$

2.1.3 Rolling contact between roller and track

The contact between roller and track can also be described as a Hertzian line contact and pressure distribution is shown in Figure 6.

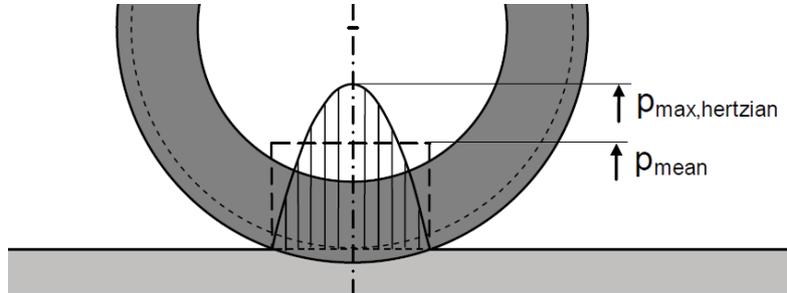


Figure 6: Hertzian pressure distribution in roller/track contact [10].

The contact between roller and track is a pure rolling contact. Although there is some rolling friction, due to hysteresis and micro-slip: When rolling, the polymer roller and track will continually be indented at the front and will elastically recover from the rear. A small fraction of the energy needed to indent is not recovered during the materials relaxation, this is called hysteresis. Under the influence of load, roller and track will deform elastically. The curved contact length of the roller reduces in length, while it increases for the track. The opposing strains at both surfaces result in micro-slip [10].

The dimensionless rolling resistance coefficient μ_{rol} is calculated in equation 2, where b is the rolling resistance coefficient of the materials. For a polymer roller on steel track, μ_{rol} is about 0,07 [5].

$$\mu_{rol} = \frac{b}{R_5} \quad (2)$$

The overall coefficient of friction μ_{total} for the chain is calculated in equation (3). It includes both sliding and rolling friction effects [1, 11].

$$\mu_{total} = \mu_{slide,equiv.} + \mu_{rol} = \mu_{slide} \cdot \frac{R_4}{R_5} + \frac{b}{R_5} \quad (3)$$

The additional pulling force on the chain due to both sliding and rolling friction can be calculated using equation (4):

$$\Delta T = \mu_{total} \cdot N_{02} = \left(\mu_{slide} \cdot \frac{R_4}{R_5} + \frac{b}{R_5} \right) \cdot N_{02} \quad (4)$$

2.2 Wear in conveyor chains

2.2.1 General overview of wear mechanisms in conveyor chains

In materials science, wear can be defined as a process where interaction of the surfaces or bounding faces of a solid with its working environment results in erosion of the material [12]. To study the wear of conveyor roller chains, it is important to know which wear mechanisms can occur. The conveyor chain wear mechanisms found in literature were listed and sorted into a tree-structure, see Figure 7 [2, 13, 14].

This research will only focus on tribological failure because a conveyor roller chain system that is well designed will fail due to tribological wear. Tribological wear can be monitored so that the chain can be replaced before breakage occurs. The most common wear mechanisms in chains with polymer rollers are: adhesive wear, abrasive wear, impact with sprocket and softening of the polymer due to heat generation. They are discussed in the next sections. Failure due to plastic deformation or fracture will occur suddenly and does not evolve gradually. Therefore it should always be avoided by choosing the load- and safety

factor for the chain sufficiently large [1]. Corrosion failure can be reduced by choosing the right materials and/or coatings for the chain, given the working environment [15-17].

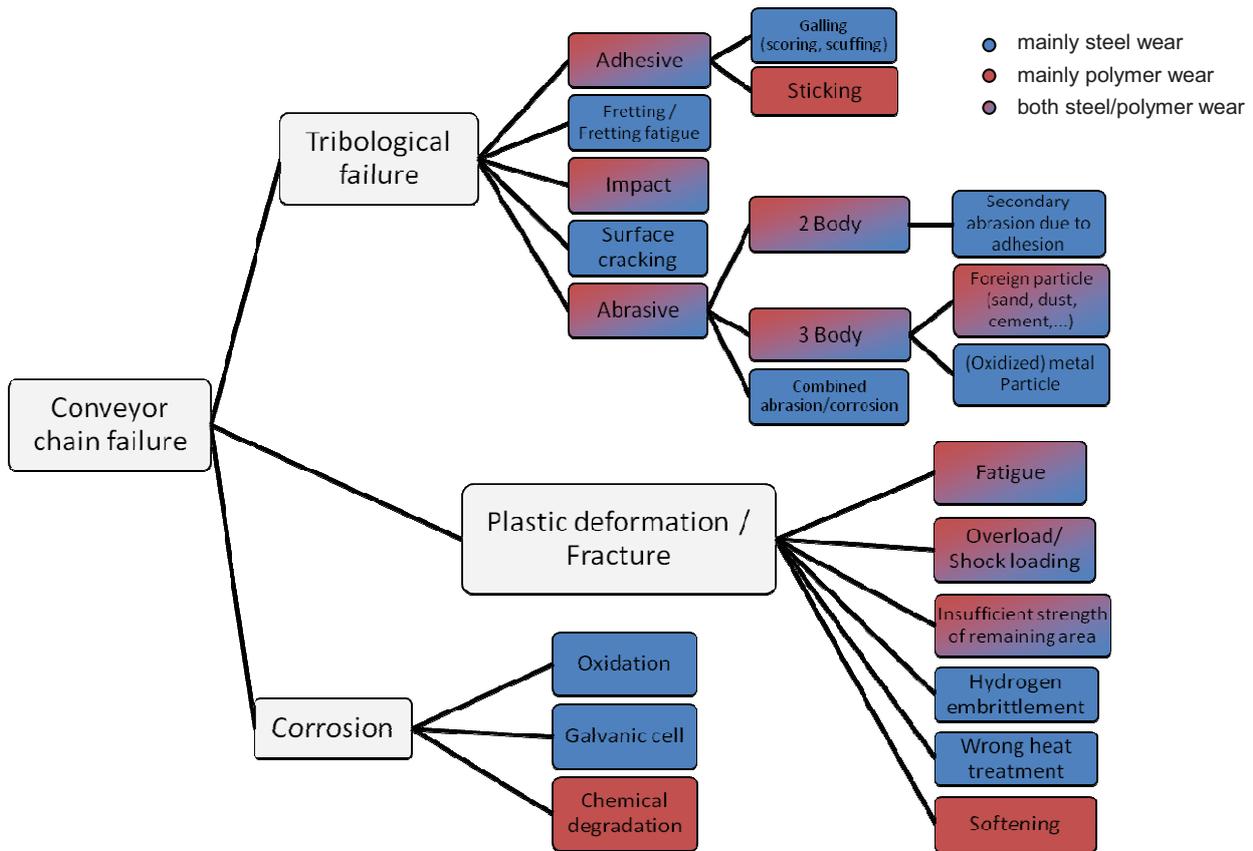


Figure 7: Wear mechanisms occurring in conveyor chains

2.2.2 Adhesive wear

Adhesive wear occurs when strong adhesive bonding between interacting asperities causes micro-welding. In a continuous movement, junctions shear off whereby material may transfer from one surface to the mating surface [10]. For unlubricated conveyor chains, adhesive wear is expected to occur between roller/bushing and roller/tracks. Galling and sticking are forms of adhesive wear. With steel-on-steel contact, galling is expected and for polymer-on-steel contact sticking of the polymer to the steel counter surface might occur.

Galling is defined as local welding of both surfaces, immediately followed by breaking of the surfaces. This will occur if the operating conditions exceed the maximum speed and/or load. Especially when the lubrication mechanism does not remove the developed heat fast enough. Galling can occur at low speeds and destroy the contact surface.

Sticking is defined as local melting of one surface to another surface. Because of the heat, the polymer roller can stick to the steel bushing resulting in roller blockage.

2.2.3 Abrasive wear

Abrasive wear occurs in two modes which are referred to as two-body and three-body abrasive wear. Two-body abrasion refers to a hard, rough surface, of which the asperity summits plough into the relative softer counter surface. The effect of abrasion is comparable with a 'micro-cutting process'. Three-body abrasion refers to hard particles between two sliding surfaces participating to the ploughing of at least one of the surfaces. Two-body abrasion may result in three body abrasion when hard wear particles are formed that subsequently contribute to the wear process, see Figure 8. Especially for materials with large difference in relative hardness. In this research, for steel vs. polymer, abrasive wear is expected to be high [10].

In conveyor chains with polymer rollers, both two-body and three-body abrasive wear is expected to occur. Sand, dust or other particles can get between the roller/bushing contact and get embedded in the polymer,

enlarging ploughing and increasing friction. In some cases, particles can act as rolling elements and thus reducing friction. Particle geometry and size are important parameters together with the properties of the polymer.

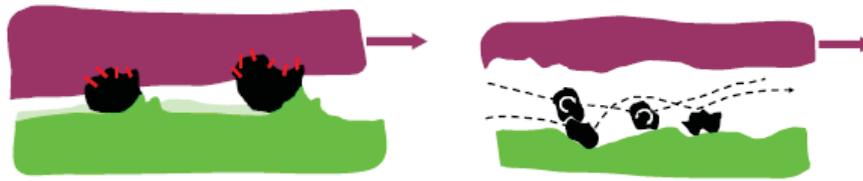


Figure 8: Two-body abrasion (left) and three-body abrasion (right) [18]

2.2.4 Impact of roller with sprocket

If a sprocket drives the chain and takes up a roller of the chain, this roller impacts against the tooth of the sprocket and is lifted due to the polygonal shape of the sprocket, this is called the polygonal effect. The impact increases with decreasing number of sprocket teeth, increasing conveying speed and increasing tensile load inside the chain. Both the roller and sprocket tooth surface can deteriorate due to impact fatigue.

2.2.5 Softening of the polymer

Softening of the polymer under load occurs when the deflection temperature is reached. This will change the material properties such as: tensile strength, hardness, sticking properties,... The softening temperature for thermoplastics is lower than the melting point. For example, the melting point of POM-H lies around 175°C, while the deflection temperature at 1,8 MPa is around 121°C [6].

2.3 Experimental set-up

Today, there are almost no reliable test-rigs available to generate and measure conveyor chain wear in a reproducible manner. A literature search revealed the following full scale test-rigs [14, 19]:

A first test rig was designed by the Central Electricity Generating Board to investigate the wear of a pin-bush chain used to lift control rods in a nuclear plant [14]. This test-rig is not designed to test roller chains.

The Chemnitz University also has some test-rigs, but mainly to investigate flat-top conveyors which do not have rollers [19]. These tests set-ups are not suitable for the testing of conveyor chains with polymer rollers.

Further, the use of the twin-disc test to investigate the roller/track wear and the pin-on-ring test to investigate bushing/roller wear was considered. But these tests were found to focus too much on the material level and not representative for the real working conditions of roller conveyor chains. Therefore a new test-rig was designed, the design constraints are discussed in section 2.3.1.

2.3.1 Design constraints

To study the wear in roller conveyor chains with polymer rollers, different conveying velocity and loading conditions have to be simulated. Therefore the test rig should allow regulation of the conveying speed, tensile force inside the chain and normal load on the rollers. Different sizes of sprockets can be used to investigate the influence of the polygonal effect or to use chains with smaller or larger pitch. The sprocket diameter can vary between 129 mm and 300 mm.

To determine the range for the conveying speed, two different sources are used. According to the Standard handbook of chain, a speed range for conveyor chains between 0,025 m/s and 0,762 m/s is commonly used [1]. In the Tsubaki engineering manual, the usable speed range speed range is between 0,25 m/s and 2 m/s [5]. Therefore, 2 m/s is chosen as an upper limit for the conveyor chain speed.

From the conveyor chain speed range and sprocket diameters, the required motor speed is determined. For the set-up a 4-pole induction motor with a rated speed of 1450 rpm is used. It is powered by a variable frequency drive (5-100 Hz). Then a planetary gearbox is required with a speed reduction of 9,8. This results in a lower velocity limit of the chain of 0,1 m/s. For testing at lower speeds, another gearbox is required which has a speed reduction of 40. With this gearbox, the lowest possible chain speed is 0,025m/s. These speed ranges are shown in Figure 9. Notice that the velocities in Figure 9 are for the sliding speed of roller/bushing interface. To relate this to actual conveying speeds of the chain, the velocities of the graph have to be multiplied with ratio R_5/R_4 . Typical values for this ratio R_5/R_4 are 2 or lower.

The maximum roller load for the polymer rollers is derived from the pv-limit diagram in Figure 9. Assume that a chain with PEEK rollers is used ($R_4=15\text{mm}$, $R_5=40\text{mm}$, roller width=10mm). The maximum roller load is than 1200 N per roller which results in a maximum Hertzian pressure of 20 MPa in the roller/bushing contact and 80 MPa in the roller/track interface [10]. This chain has a pitch of 50,8 mm thus 9 rollers will be in contact with the 500 mm long track. This results in a total normal force F_n of 10,8 kN that has to be applied on the chain.

The motor for the test-rig should deliver 2 kW of shaft power. If an efficiency of 50% for the reduction and sprockets is taken into account, the following motor power limit is obtained, shown in Figure 9. Note that it lies above the pv-limit of the polymers. The working area of the test-rig, obtained by the constraints above, is grey coloured.

The test-rig is designed to simulate tribological failure of the chain, breakage of the chain should never occur. In normal conditions the working load, this is the tensile force inside the chain, is generally taken 1/8 of the breaking load. For use in abrasive and unlubricated conditions, load factors up to 1/18 of the breaking load are used [2, 11]. In this test set-up, a tensile force up to 1/5 of the breaking load is used to generate sufficient quick wear. The maximum tensile force that thus must be applied is 20 kN.

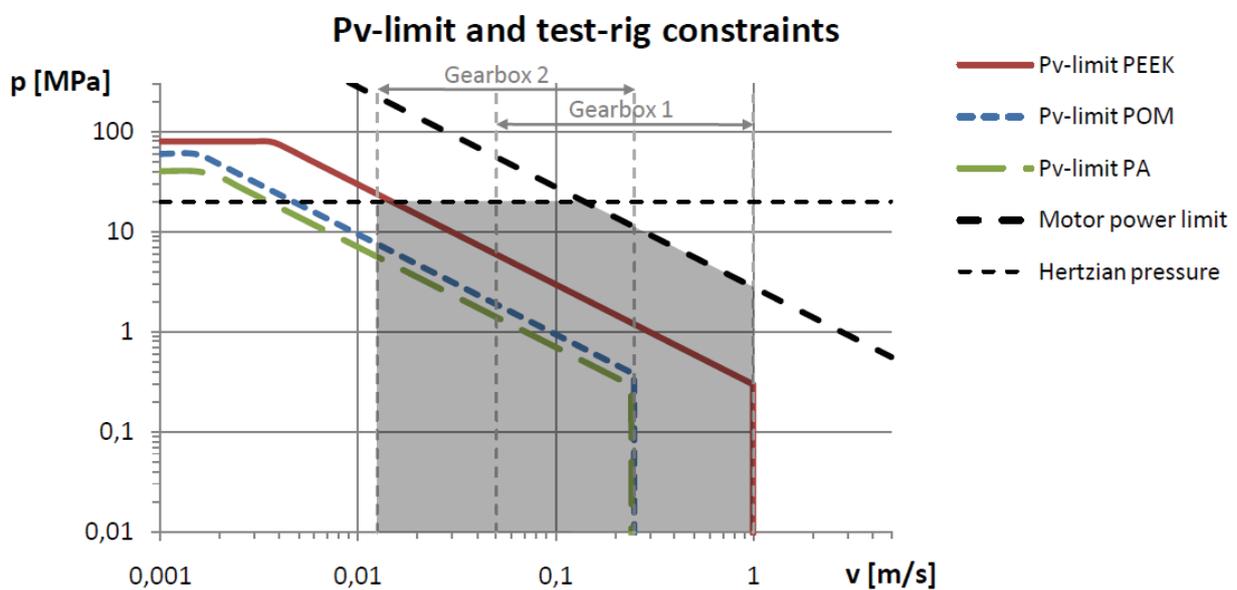


Figure 9: Pressure velocity limit of different polymers and test-rig limitations

2.3.2 Design of the experimental set-up

The experimental set-up allows testing of different types of conveyor chains. It is possible to independently regulate the conveying speed, tensile force inside the chain F_t and normal load F_n applied on the rollers. Sprocket diameters from 129 mm to 300 mm can be tested. The design is shown in Figure 10.

The mechanism to apply tensile force on the chain is *green coloured*. The maximum force that needs to be applied is 20 kN. A pneumatic piston cannot directly deliver this force. Therefore, a lever mechanism with a ratio of 1/5 is used. The pneumatic piston should then deliver 4 kN, which is possible. This force, produced by the piston, is transferred by the lever mechanism to the take-up units and then to the take-up shaft. The take-up units allow displacement of the shaft up to 2% elongation of the chain. Sprockets are clamped on the take-up shaft and transfer the tensile force to the conveyor chains. On the other side of the test-rig, the driving shaft is supported by two fixed plummer-block bearing units. The driving shaft is driven by a motor and planetary gear box (not shown).

The *red coloured section* shows how the normal force is applied to the conveyor chains, see Figure 10. The maximum normal force F_n that can be applied is 10,8 kN. This force is delivered by a pneumatic piston and is transferred to the upper running surface and then to the rollers of the middle conveyor chain. The loading principle of the chain is shown in Figure 11: The chain for testing is in the middle, it is supported by two chains, one on each side. The supporting chains are connected with the middle chain by means of distance bushings and bolts and transfer the normal load to the lower running surfaces. The supporting chains do not contribute to the tensile strength of the middle chain because their outer side plates are removed. They only exist of inner shackles which function as support rollers.

The running surfaces are interchangeable to test different track materials. The distance between the running surfaces can be adjusted to the dimensions of the chains. This is possible by displacing the supports of the tracks along the vertical slots in the chassis. Additionally the configuration of the running surfaces can be altered (not shown) so that one track is on the bottom and the two supporting tracks are on top.

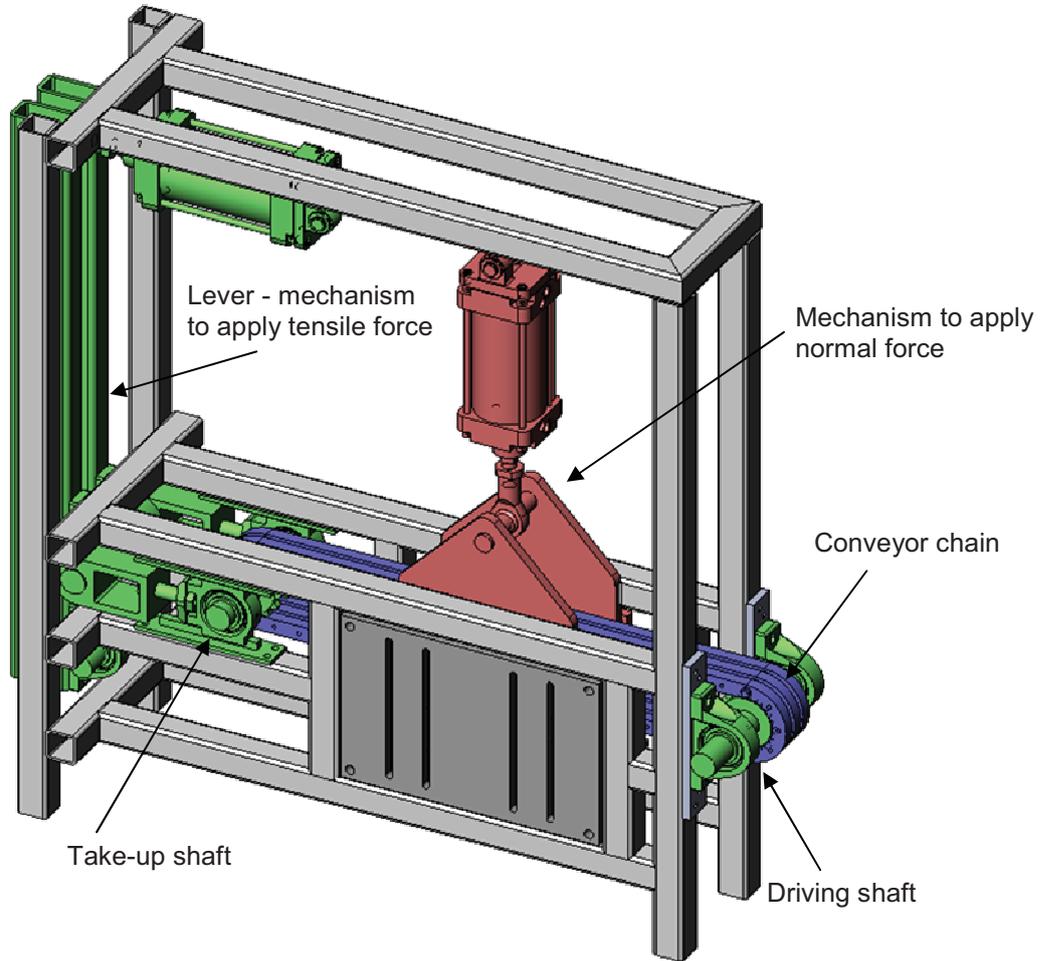


Figure 10: CAD-drawing of the designed test-rig

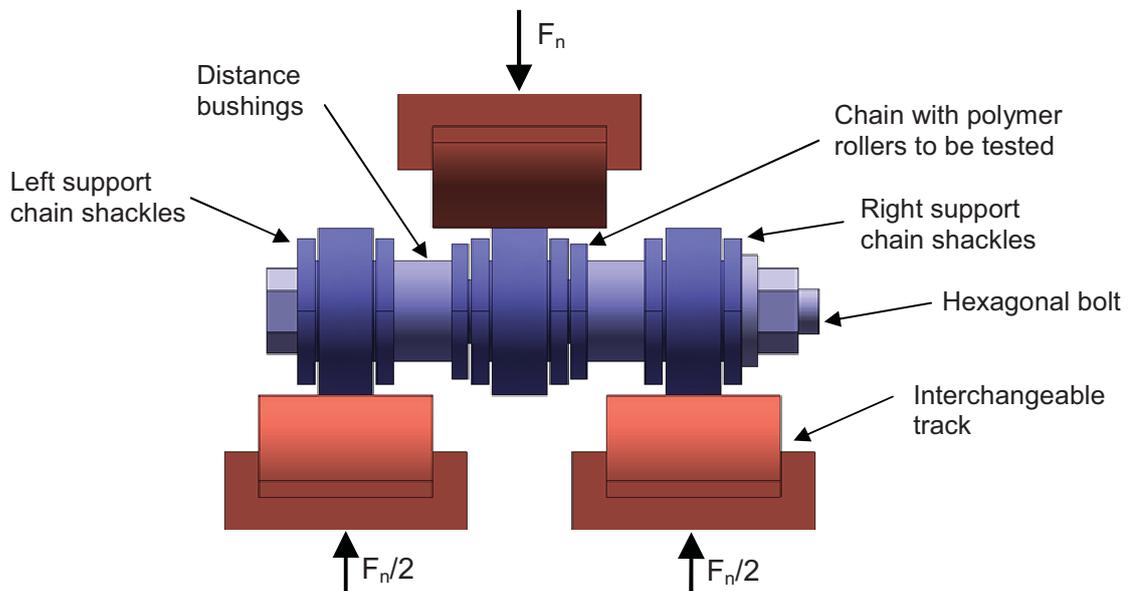


Figure 11: Loading principle of the chain

2.3.3 Instrumentation

Sensors will be placed on the test-rig to measure the applied forces and occurred wear. To accurately measure the tensile force, a load cell is placed between the lever and take-up units. To measure the applied normal force a load cell is applied between the cylinder and its support. To monitor the elongation of the chain, a linear variable differential transformer (LVDT) is used. An optical measuring device is used to measure the change in diameter due to wear of the polymer rollers. The signals from the instruments are captured by a DAQ-card and processed using a PC. Off-line measurements are performed before and after testing to measure the dimensions of the chain components, surface roughness and hardness.

3 CONCLUSIONS

Conveyor chains with polymer rollers are widely used. Mostly because they are capable of working without any lubrication and have good corrosion resistance. From the study of the contact mechanics in a chain, the sliding contact between roller/bushing and rolling contact between roller and track were found to be the most wear critical areas. The wear mechanisms occurring with conveyor chain were listed. For conveyor chains with polymer rollers, the expected wear mechanisms are adhesive wear, abrasive wear, impact with sprocket and softening of the polymer due to heat generation. Existing test-rigs were found not suitable to examine the wear of conveyor chains with polymer rollers. Therefore a new test-rig was designed. The design constraints for the normal load and conveying velocity were obtained from the pressure-velocity limit of frequently used polymers. The breaking load of the chain was used to determine the tensile force in chain. Experiments performed on this test-rig will give better correspondence with the wear mechanisms occurring in real conveyor chain applications.

4 NOMENCLATURE

p	pressure	MPa
v	velocity	m/s
μ	coefficient of friction	-
K	specific wear rate	mm ³ /Nm
F_t	tensile force inside chain	N
F_n	normal force applied on chain	N
ΔT	additional tensile force due to resistance	N
O_i	origin of local coordinate system of component i	-
e_{ij}	eccentricity of component i versus j	m
F_{ij}	force from component i on j	N
T_{ij}	tangential force of component i on j	N
N_{ij}	normal force of component i on j	N
R_i	radius of circle i	m
b	rolling resistance coefficient	mm

5 ACKNOWLEDGEMENTS

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