Negative impressions of the rope's surface in the grooves of sheaves and drums

Quite regularly on cranes and other rope drives impressions in the grooves of the sheaves or drums can be found which look like the negative imprint of the wire rope in use (Fig. 1). The reasons for the occurence of such damage have not been fully cleared up yet. This treatise investigates the phenomenon.

Figure 1: Wire rope sheave with negative impressions

A wire rope rests on a sheave with the crowns of its outer strands at a limited number of contact points (Fig. 2). As in these few points the reaction forces to the line pull of the wire rope are transmitted, quite often relatively high pressure forces between the wire rope and the sheave occur in these points. These high pressure forces in combination with tiny relative motions between the wire rope and the sheave when the wire rope is spooled on and off are responsible for the material abrasion on the sheave and rope surface. Under normal circumstances this abrasion will be distributed very evenly along the circumference of the sheave. It requires very special conditions for a negative impression of a wire rope to occur on a sheave or drum.

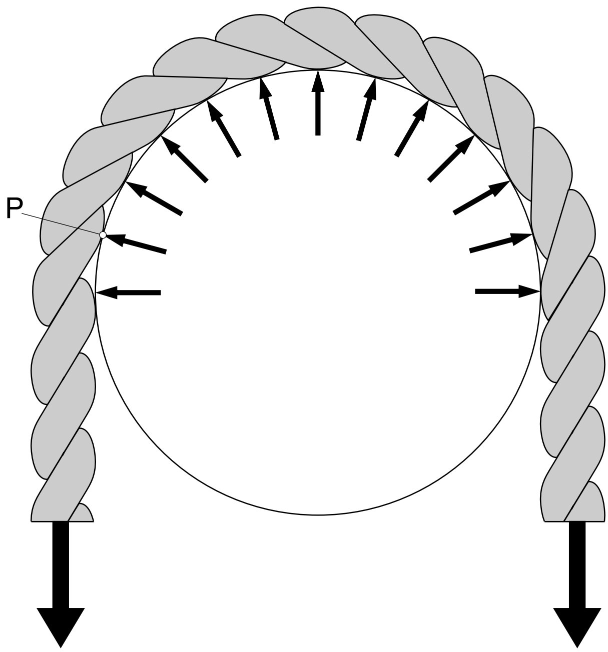

Figure 2: Contact conditions

A wire rope sheave with a small angle of rotation

Let us first look at a sheave which during a typical operation cycle does not carry out a full rotation of 360°. Point P indicates the position where a strand crown lies at the beginning of the operation cycle (Fig.2).

If, for example, the sheave carries out a rotation of 90° anti-clockwise, the crown lying in point P will leave the bottom of the groove. During the rotation of the sheave back into the starting position it will come to lie exactly in the same point P.

If the sheave carries out the very same motion again and again, an abrasion of material will occur in point P. Areas in the surroundings of point P, however, will never be in contact with the rope spooling on and off, so that in the surroundings of point P the original geometry of the grooves will be preserved. The result is that the wire rope will dig into the groove in point P and the other points of contact and, by doing so, will create a negative impression of its surface. Consequently, sheaves which carry out only very small rotations always fulfill the geometrical conditions for the appearance of negative impressions.

Rule 1:
Sheaves with a small angle of rotationare prone to negative impressions.

Sheaves with great angles of rotation

Sheaves which only carry out small angles of rotation are rather exceptional. Normally great rope lengths travel over the sheaves, so that during a typical operation cycle a great number of rotations is carried out. Let us now look at the conditions for that case.

At the beginning of the operation cycle a strand crown rests on the groove in point P (Fig.2). If the sheave carries out a small angle of rotation, the strand crown lying in point P will leave the bottom of the groove. After a rotation of 180° the wire rope will come to lie again in the neighbourhood of point P with a different strand crown. It is likely that the strand crown will not exactly hit point P but, for example, a point 1mm away from point P. After one more rotation of 360° the new point of contact will have moved away from point P by another millimeter. In this way it is guaranteed that for spooling of a greater rope length the contact points of the strand crowns are evenly distributed on the sheave's surface, so that the unavoidable material abrasion is evenly distributed along the circumference of the sheave.

Nevertheless, under certain circumstances a wire rope can dig into the sheave even if the sheave carries out a great number of rotations during a typical operation cycle.

The geometrical conditions for the occurence of negative impressions

The number and distance of the contact points of a wire rope on a sheave depend on the number of outer strands, the effective diameter and the lay length of the rope. In a straight rope the distance between the strand crowns amounts to

$$A_{straight} = L_0 / z$$

When the rope is bent it amounts to

$$A_{bent} = L_0 \bullet D / (z \bullet (D + d)),$$

with

L_0 = effective lay length of the rope
z = number of outer strands
D = diameter of the sheave at the bottom of the groove
d = effective rope diameter

The geometrical conditions for the occurence of negative impressions of a wire rope in the groove are given if point P is hit by a strand crown on every complete rotation of the sheave. This is exactly the case if the circumference of the sheave at the bottom of the groove is a whole number multiple of the distance of the strand crowns of the bent rope. In this case the following equation applies:

$$C = n \bullet A_{bent}$$

or

$$C = n \bullet L_0 \bullet D / (z \bullet (D + d)),$$

with

C = circumference of the sheave at the bottom of the groove
n = natural number.

If, for example, the circumference of the sheave is exactly 80fold the distance of the strand crowns Abent (n=80), point P will be hit by a strand crown after every full revolution of the sheave. It will be hit by the 80th, the 160th, 240th etc. strand crown of the rope.

Therefore increased material abrasion will take place in point P, while the surroundings of point P will be left in their original state. As a consequence we will again obtain a negative impression of the wire rope in the sheave.

If a sheave carries out a greater number of revolutions per operation cycle, the occurence of a negative impression of the rope into the surface of the groove is to be expected if the circumference of the sheave in the bottom of the groove is a whole number multiple of the distance between the strand crowns of the bent rope.

Rule 2:
Sheaves with a great angle of rotation are prone to negative impressions, if the sheave circumference is a whole number multiple of the distance of the strand crowns in bent condition.

Ineffective measures to avoid negative impressions

Guided by the previous explanations one might be tempted to correlate the factors of influence in a way that negative impressions cannot occur. As an example, the diameter of the sheave could be deliberately chosen in a way that the circumference of the sheave in the bottom of the groove is 3 mm greater than a whole number multiple of the distance of the strand crowns in a bent condition. On such a sheave, the point of contact of the strand crowns will be shifted by 3mm with every revolution, so that at the beginning a very uniform material abrasion will occur.

However, as a consequence of that uniform material abrasion the sheave diameter will decrease continually with increasing number of operation cycles until the sheave diameter is reduced by about 1mm and therefore the sheave circumference is reduced by 3 mm. From then on point P will again be hit again and again by the crown of a strand with every revolution of the sheave. The mechanism explained above will therefore again create increased material abrasion in point P, whereas the neighbouring zones of P will no longer be subjected to further change. Therefore negative impressions will suddenly occur, although uniform abrasion has taken place.

Rule 3:
Do not try to correlate the circumference of the sheave with the lay length of the rope.

One could also be tempted to correlate the rope diameter or the lay length of the rope and by this the distance of the strand crowns in a way that the geometrical conditions for negative impressions are avoided. But a wire rope changes its lay length and its effective diameter due to setting effects, especially at the beginning of its operating time, in a way not exactly predictable, so that also these measures will not be successful.

Rule 4:
Do not try to adapt the wire rope lay length and the effective wire rope diameter to the circumference of the sheave.

The use of hardened sheaves which are supposed to better resist material abrasion does not always lead to the desired result in practical operation. Wire ropes are manufactured of rope wires having a very high tensile strength and a very great hardness. A rope wire with a nominal tensile strength of 1960 N/mm2, which is quite common today, has a surface hardness HB30 of more than 5000 N/mm2. These values are not achieved by hardened sheaves, so that in the combination sheave/rope wire the wire will always be the harder partner. Therefore the material abrasion will take place preferably on the sheave. The situation is aggravated by the fact that the material abrasion will possibly occur along a great length of a rope, whereas on the sheave it is concentrated on the short piece of the sheave circumference.

Rule 5.
Don't expect a hardened sheave to solve your problem.

Also the use of elastic sheave materials, which are supposed to reduce the pressures in the point of contact by improving the bearing surface (Fig. 3), does not always show the desired effect. If the geometrical conditions are given, the wire rope will dig into a plastic sheave as quickly as into a steel sheave.

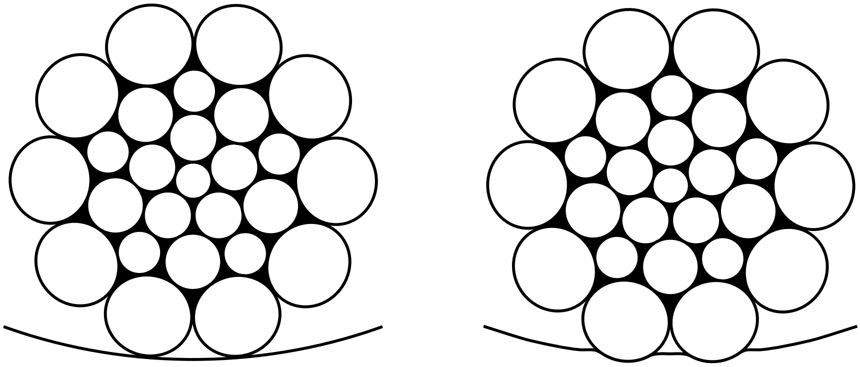

Figure 3: Contact conditions on steel (left) and on plastic sheaves (right)

Rule 6:
Don't expect a plastic sheave to solve your problem.

Occasionally cast steel is recommended as sheave material. The graphite content is supposed to have lubricating effects reducing the amount of material abrasion.

Mechanisms counteracting negative impressions

What has been said so far might lead to the assumption that impressions of wire ropes in sheaves are unavoidable. Fortunately, however, there are also mechanisms which counteract the formation of negative impressions of wire ropes in sheaves.

A slight rotation of a rope around its own axis during service can avoid negative impressions, even if the geometrical conditions mentioned above are met. Even if according to formula 1 during every revolution of the sheave point P is met by a strand crown, this contact will not take place, because after one revolution of the sheave the rope will have carried out a slight rotation, so that now point P will not meet the strand crown but the valley lying next to the crown.

It can be seen in practice again and again that installations with no fleet angle for the wire rope (which therefore will not subject the rope to rotation) are especially prone to negative impressions.

Rule 7:
Wire ropes subjected to rotation around their own axis are less likely to create negative impressions.

Another mechanism counteracting the formation of negative impressions is the continuous slight variation of the wire rope lay length caused by varying line pulls. The continuous changes in lay length cause a continous slight shift of the contact points on the sheaves leading to uniform material abrasion.

Practice has shown that rope drives with only limited changes in line pull or cranes with a high dead load are more prone to forming negative impressions than installations where the level of line pull changes continually and where the dead load is small.

Rule 8:
Frequent changes in linepull and great changes in the amount of linepull reduce the risk of negative impressions.

Successful measures to avoid negative impressions

As mentioned above, material abrasion on the sheave occurs as a consequence of slightest relative motions between wire rope and sheave. It therefore stands to reason that the amount of abrasion can be reduced by using appropriate wire rope lubricants. Regular relubrication of steel wire ropes during service counteracts the formation of negative impressions.

Rule 9:
Lubricating and relubricating the steel wire rope ounteracts the formation of negative impressions.

On the other hand, a wire rope working in a highly abrasive environment where, for instance, dust and sand particles always come to lie between the wire rope and the sheave, would show exactly the opposite effect: In an abrasive environment, the formation of negative impressions is more likely.

As mentioned above, a slight rotation of a rope around its own axis successfully prevents the formation of negative impressions. This circumstance can be taken advantage of, as the following example will show:

The largest automatic stacker in Europe showed negative impressions of the wire rope in the brand-new sheaves after only 3 weeks of service. Obviously, the geometrical conditions described above were given for this installation. In addition, the wire ropes showed no rotation at all, because the stacker was designed to have no fleet angles between the wire rope and the sheaves. The dead load of the installation was extremely high, therefore there was no significant change in lay length between a loaded and an unloaded condition. The stacker was operated with a left-hand lay rope working on a right-hand drum and a right-hand lay rope working on a left-hand drum.

It was decided to take off the ropes and install the left hand lay rope on the left hand drum and the right hand lay rope on the right hand drum. The ”wrong“ direction of lay led to an increased twisting of the ropes by the drums, which was desired in this case. After only a few days of operation, the ropes had ground off the profile of the impression, and due to the deliberate rotation of the ropes, the grooves stayed smooth afterwards.

Because of the danger of structural damage of the wire ropes measures like this one should only be employed with wire ropes having a great structural stability, such as wire ropes with a plastic layer between the rope core and the outer strands. In addition, the manufacturer of the installation and/or the rope manufacturer should be consulted.

Rule 10:
Deliberate rotation of the rope by using the ”wrong“ direction of rope lay can help to avoid negative impressions.

Rule 11:
A rope with the opposite direction of lay can grind off the negative impressions created by the previous rope.

A very effective means against the formation of impressions in sheaves is the use of wire ropes with compacted outer strands. The outer wires of a compacted strand (Fig. 4) have been designed to fit the surface of the grooves much better than those of conventional outer strands (Fig. 5). By using ropes with compacted outer strands, the bearing surfaces are increased considerably and consequently the pressures and the material abrasion are reduced accordingly.

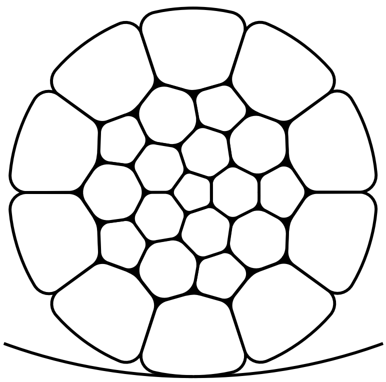

Figure 4: Compacted strand

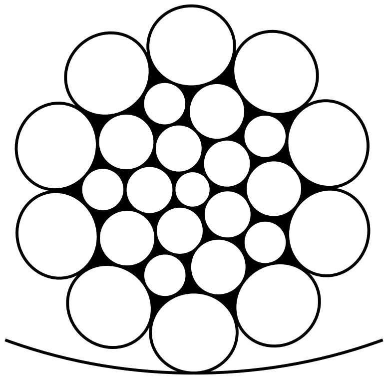

Figure 5: Conventional strand

What can be done if negative impressions have occurred?

A wire rope which has dug its own profile into the bottom of a groove will find relatively favourable bearing conditions. While initially every strand crown only had point contact with the groove (Fig. 2), it is now supported by a greater area (Fig. 6). As a result of the impression, the service life of the rope will increase in most cases.

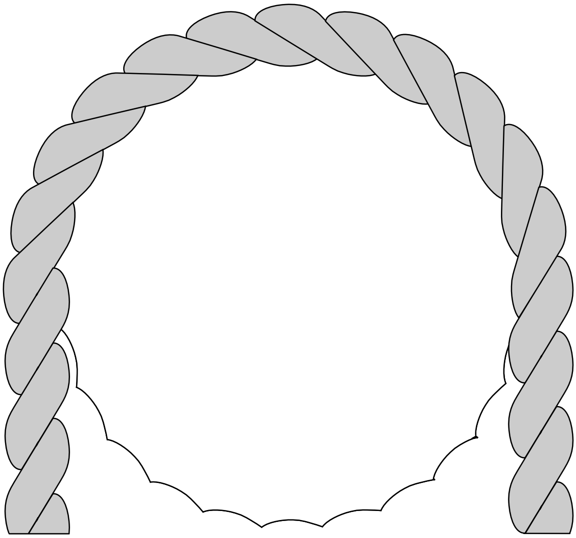

Figure 6: Good contact conditions for the old rope

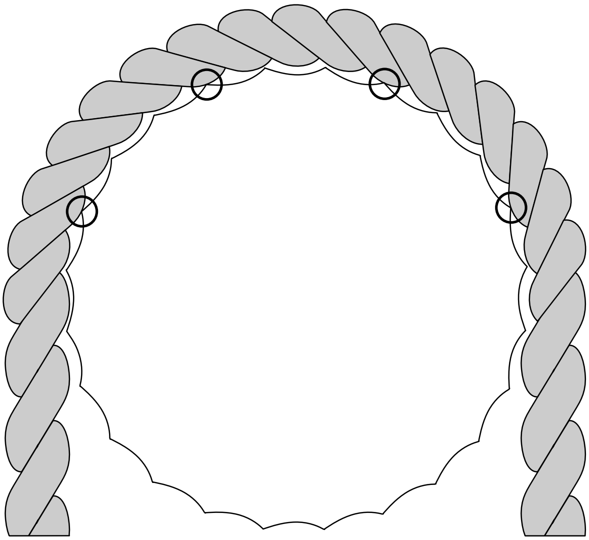

Figure 7: Very bad contact conditions for the new rope

If the rope that has caused the impression is discarded, the replacement rope, however, will find very unfavourable conditions on the imprinted sheave, as its diameter and its lay length will not match the profile on the sheave (Fig. 7). Its very few points of contact will be subjected to very high pressures which will reduce its service life tremendously.

Additionally, the rope will try to adopt the lay length of the profile in the groove and will therefore tend to structural damage, e. g. cork screw formation. Therefore, if severe impressions are found, the sheaves should be replaced or machined when a new rope is installed.

Rule 12:
A negative impression normally does not reduce the service life of the rope that created the impression.

Rule 13:
If severe impressions are found, the sheave must be replaced or machined when a new rope is installed.

With many rope drives, however, replacing the sheaves is very costly. That is the reason why many users prefer to install a rope with a direction of lay opposite to the one which created the impression. For instance, if the impression was created by a right hand lay rope they would install a left-hand lay rope. This would avoid the danger that the new rope would try to squeeze itself into the old profile. In addition, the new rope will try to grind off the old profile. So, before such a measure is taken, the supplier of the machine and/or the rope should be consulted.

Because of the increased material abrasion (which is even desired in this case), usually ropes with compacted outer strands are used, which provide more favourable bearing conditions, have more robust outer wires and can withstand the increased material abrasion much better because of their higher metallic cross-sectional area. Due to increasing demands on the structural stability, wire ropes with a plastic layer between the steel core and the outer strands are preferably used.

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