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The use of swivels with steel wire ropes

Summary

Whether or not a swivel should be used with steel wire ropes on cranes depends upon the rotation characteristics of the rope and the type of swivel. This paper defines three categories of steel wire rope (non rotation resistant, semi rotation resistant and rotation resistant) and describes four types of swivel (free spinning, lockable, self-locking and powered). Guidelines are given for which type of swivel could or should be used with each category of rope.

1. Introduction

In the past, the question whether or not steel wire ropes may or even should be attached to a swivel has been the subject of great debate. The answer to the question depends on the type of steel wire rope and the type of swivel used.

Wire rope experts from the USA and Europe working on the ISO wire rope standards have recently agreed to classify steel wire ropes into three different groups based on their rotational characteristics:

- non rotation resistant ropes
- semi rotation resistant ropes
- rotation resistant ropes

It is intended to define the borders between these categories in such a way that the classification will allow an easy answer to the question whether a specific wire rope may be used with a free spinning swivel or not: If the wire rope is classified as rotation resistant, it may. If it is classified as semi rotation resistant or as non rotation resistant, it may not.

Verreet (2000) has proposed a simple, easily repeatable test to determine the relevant rope data: The angular rotation of a rope length of 150 times the nominal rope diameter is measured under a line pull of 10% of the rope's minimum breaking strength (an average crane rope line pull). According to the proposal, ropes should be classified as:

- rotation resistant

  for a rotation less than 20 degrees;

- semi rotation resistant

  for a rotation between 20 degrees and 180 degrees; and,

- non rotation resistant

  for a rotation more than 180 degrees.

Rope manufacturers from the USA and Europe are at the moment collecting test data to finalise the proposed borders between the groups.

We will now discuss three scenarios, involving wire ropes from all three categories (Verreet, 1997):

2. Scenario 1: Lifting a load using a non rotation resistant rope

Let us lift an unguided 10t load with a steel wire rope of the design 6 x 36 IWRC (Figure 1) in a single fall lift: The wire rope will tend to unlay, causing the load to rotate around the rope's axis. We obviously have a problem: rotating masses of 10t can be very dangerous!

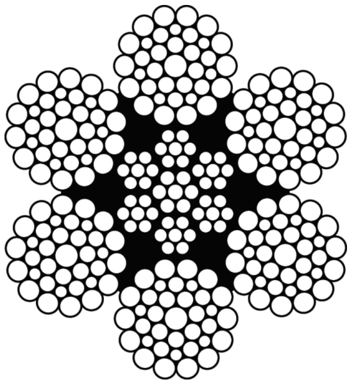

Figure 1: Cross section of a 6 x 36 IWRC steel wire rope

Let us now perform the same lift with a free-spinning swivel installed between the 10t load and the wire rope: Now the rope will rotate the swivel, but not the load. Our initial problem seems to be solved.

But we have introduced other, less visible dangers to our reeving system:

During every lift, our wire rope will operate in an unlayed condition, in which its breaking strength is considerably reduced, compared to its catalogue breaking strength. Therefore our crane will operate with a severely reduced design factor.

While operating in the unlayed condition, the IWRC of the rope will be over-proportionally loaded, increasing the danger of internal wire breaks which can not be detected by a visual rope inspection.

In addition, whenever we will load and unload our wire rope, the swivel will allow the rope to rotate back and forth. Chaplin et al. (1999) have shown that the tension-torsion fatigue caused by this rotation will reduce the wire rope's endurance by a factor of about ten.

3. Scenario 2: Lifting a load using a semi rotation resistant rope

Let us now lift an unguided 10t load with a wire rope 18 x 7 (Figure 2) in a single fall lift. This rope has a first layer of 6 strands closed in one direction around the rope core (which might be a fibre core or a strand) and a second layer of 12 strands closed in the opposite direction.

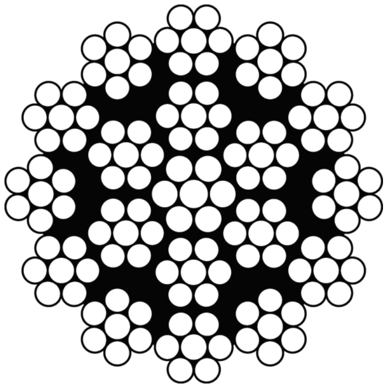

Figure 2: Cross section of a 18 x 7 steel wire rope

The six inner strands, acting on a short lever arm, will try to rotate the rope in the one sense. The outer strands, being twice as many in number and acting on a lever arm exactly twice as long, will try to rotate the rope with a moment four times as large, but acting in the opposite sense. If the two layers were acting in the same direction, the resulting moment would be 5 times as large as the moment created by the inner layer. But as the outer layer is acting in the opposite sense, the resulting moment is only three times as large as the moment created by the inner layer, and it is acting in the opposite sense. This simple calculation shows that closing the inner layer in a sense opposite to the outer layer reduces the moment to about 60% of the original figure. But that is not sufficient: the rope will unlay, again causing the load to rotate around the rope's axis.

Let us now perform the same lift with a free-spinning swivel installed between the 10t load and our 18 x 7 wire rope: As in the previous scenario, the swivel will rotate, but not the load. Again, our initial problem seems to be solved.

But as in the previous scenario, we have introduced other, less visible dangers to our reeving system:

During the lift, the rope will operate in a slightly unlayed condition. Interestingly, although the amount of rotation is less than in the first scenario, the rope's breaking strength is reduced much more than in the case of the 6-strand rope.

This is because the unlaying of the rope will not only lengthen the rope but also shorten the inner strand layer which is closed in the opposite direction. So already a moderate rotation of the swivel will remarkably unload the outer strands and severely overload the inner strand layer.

Because the core is working in an over-proportionally loaded condition during every lift, the inner elements of the rope will fatigue much faster than the outer, under-proportionally loaded rope elements. During a visual rope inspection, however, only the outer wires will be visible. They might still be in very good condition while the core is already in an unsafe state.

During loading and unloading, the swivel will always rotate back and forth, causing a series of effects: The tension-torsion stresses caused by the rotation will considerably reduce the wire rope's fatigue strength, especially in the vicinity of the swivel.

In addition, twist will accumulate in the reeving system: Non rotation resistant ropes (scenario 1) and semi rotation resistant ropes (scenario 2) will rotate the swivel in the opening sense during loading and in the closing sense during unloading. It is a common perception that the number of turns in the opening sense will be the same as in the closing sense, leaving the rope in a non-twisted state after unloading. This, however, is not true, as the following case study will illustrate:

4. Case study: Twist in the reeving system caused by a free spinning swivel

A new, semi rotation resistant rope as in Figure 2 has been installed on a simple crane with one sheave and one drum (Figure 3). We have made sure that the rope has not been twisted during installation. The wire rope is attached to the hook by means of a free spinning swivel.

When lifting a load off the ground, the rope length between the sheave and the swivel will unlay by rotating the swivel. In our example the swivel will perform eight revolutions, represented by eight dots on the rope (Figure 4).

When lifting the load further, part of the twisted rope length – in our example half of the twisted rope length – will move over the sheave. After this operation, half of the revolutions induced by the swivel, represented by four dots, will be found between the sheave and the drum (Figure 5). In this area a relatively severely twisted rope zone meets a section of non-twisted rope.

The twisted zones will transfer part of their twist to the as yet non-twisted zones, i.e. the four revolutions will be spread evenly across the whole rope length between the sheave and the drum (Figure 6).

Now the crane is moved into a different position or just slews, and the load is set down. When lowering the hook, part of the twisted rope length (in our case half of it) will travel from the length between the sheave and the drum into the line to the swivel.

In our example, two revolutions leave the section between sheave and drum (Figure 7). At the same time non-twisted rope spools off the drum into the same stretch. The two revolutions remaining between the drum and sheave now spread evenly in that section, while the line attached to the swivel returns to its non-twisted state once the load is put down (Figure 8).

We have now returned to the starting position, and the process described above could start all over again. We started with a non-twisted rope, but after only one lifting operation two complete revolutions have entered the reeving system. The twisted zones are trapped between the sheave and the drum and cannot unlay at the swivel to regain their initial, non-twisted state. On the contrary, with every additional lift, the amount of twist will increase even further.

It is a fallacy to believe that twist introduced into the rope by loading it will be eliminated when the rope is unloaded. Due to the "mixing phenomenon", part of the twist will always remain in the system. After poisoning a barrel of wine with a glass of arsenic, it cannot be expected to become drinkable again just by skimming off a glass of the mixture from the barrel.

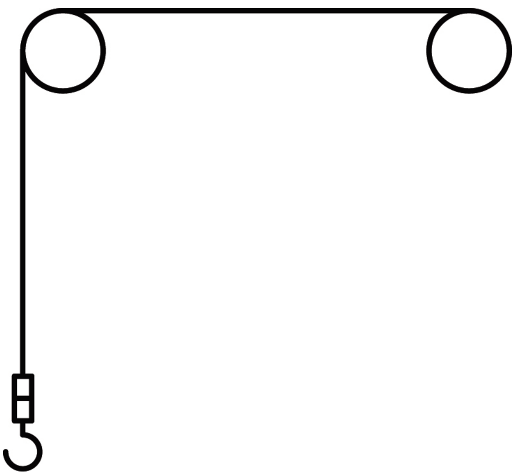

Figure 3: Before lifting the load the wire rope is non-twisted

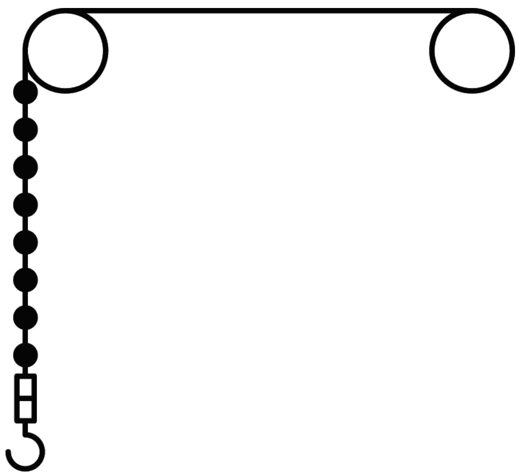

Figure 4: When the load is lifted, the swivel carries out eight complete revolutions

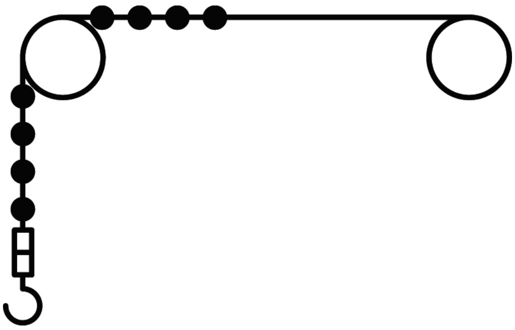

Figure 5: While lifting the load, half of the twisted rope length passes over the sheave

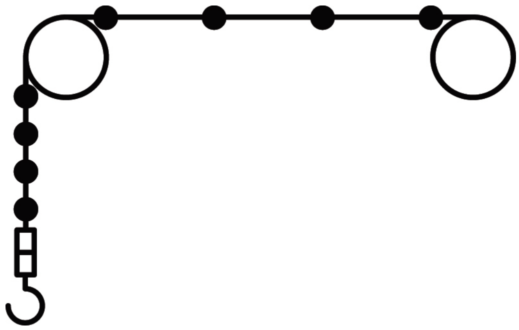

Figure 6: The twist spreads evenly along the rope length

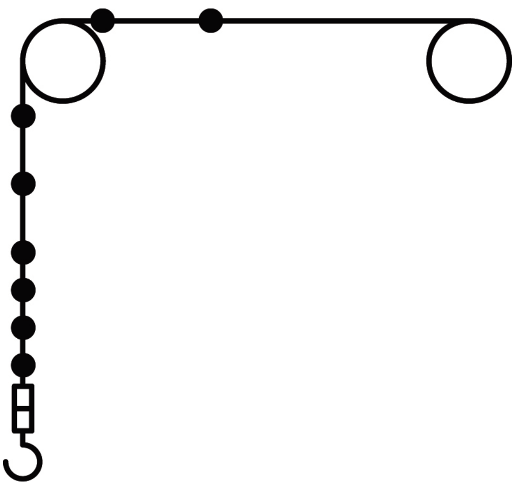

Figure 7: Part of the twisted rope length runs back over the sheave

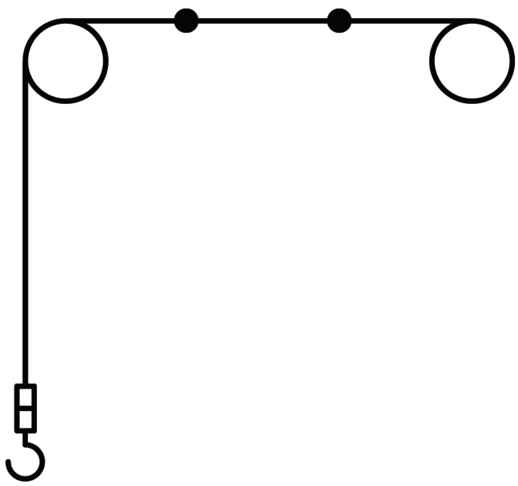

Figure 8: After one lifting operation two revolutions remain within the reeving system

The increase of twist within the system in the course of further lifting operations may lead to different consequences for the rope. The twist might overstress some elements of the rope and lead to their premature failure. More often, however, the twist will lead to differences in the lengths of strands in different rope layers, which then results in the formation of birdcages or corkscrews.

Figure 9 illustrates an example of birdcaging on the drum. Not many wire rope experts will have the experience to recognise the fact that this rope deformation at the one end of the rope has been caused by the swivel attached to the rope at the very other end. Mislead by a comment in ISO 4309 (which will be eliminated in the next version of the standard), they will explain the damage as a “result of a shock-load”.

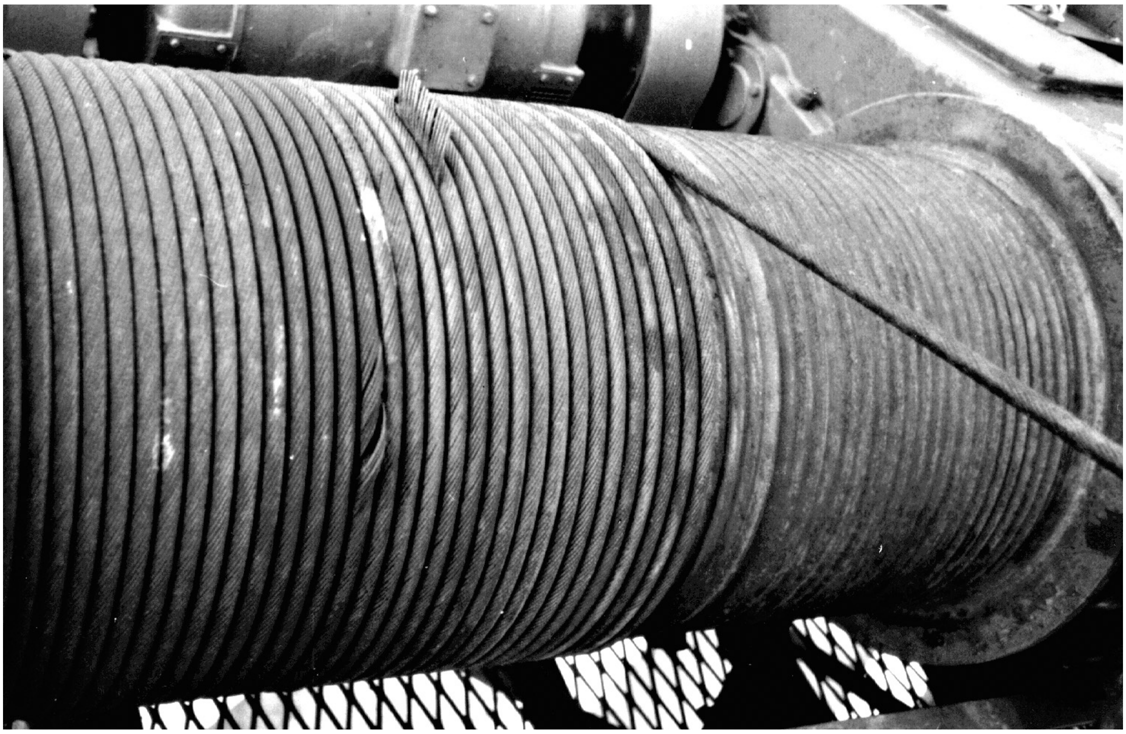

Figure 9: Birdcaging on the rope drum

When a twisted rope is unloaded abruptly, a very dangerous situation called “slack-rope formation” may occur. What actually happens is that when the heavily twisted rope is unloaded it manages to rid itself of part of the twist by forming a loop (Figure 10). When the rope is loaded again, the loop might tighten and form a kink. This can happen within a split second and might not be noticed in time by the crane operator – the consequence could well be a broken steel wire rope.

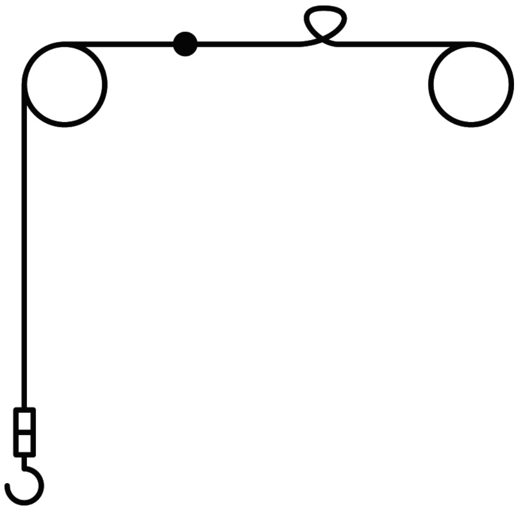

Figure 10: Formation of a loop when a twisted rope is sagging or slack

5. Scenario 3: Lifting a load using a rotation resistant rope

Let us now lift an unguided 10t load with a 40-strand special wire rope (Figure 11) in a single fall lift. This rope has two layers of 21 strands closed in parallel lay in one direction around the centre strand and a third layer of 18 strands closed in the opposite direction.

The inner strands exceed the outer strands by about 20% in number and by about 25% in mass. This compensates for the shorter lever arms of the inner strand layers and guarantees for a well balanced steel wire rope. When lifting the 10t load, the rope will have no tendency to unlay, and therefore the load will not rotate.

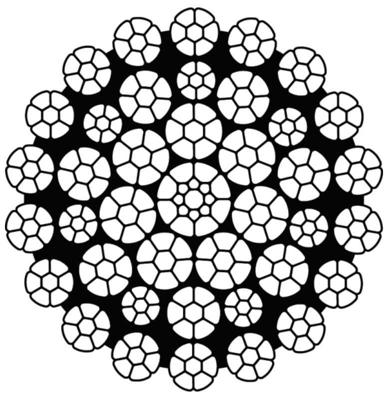

Figure 11: Cross section of a 40-strand steel wire rope (Casar Powerlift)

If a free-spinning swivel is installed between the rope and the load, the swivel will not rotate back and forth during loading and unloading.

Although attached to a swivel, the rope will not operate in an unlayed condition and therefore its breaking strength will remain unaffected. The rope’s independent wire rope core will not be overloaded, and this in turn will reduce the danger of internal wire breaks.

Because the rope will not rotate back and forth during loading and unloading, it will not suffer from tension-torsion fatigue. Its endurance will remain unaffected, and because the rope will not unlay under load, the twist built-up and the formation of birdcages described in the case study above will be avoided.

So obviously in this third scenario the installation of a free spinning swivel will not adversely affect the wire rope performance or safety.

On the contrary, under certain circumstances the installation of a free spinning swivel will have a very positive effect: If a rope enters a sheave under a fleet angle, it will first touch the sheave at the flange, and from this point of contact it will roll down into the bottom of the groove (Figure 12). This mechanism will severely twist the rope. Unfortunately, rotation resistant steel wire ropes are very sensitive to any kind of imposed twist, and rope deformations such as birdcages might be the consequence. In such a case a swivel installed in the reeving system will allow a rotation resistant rope to regain its non-twisted state by moderately rotating the swivel.

The swivel would in addition allow any twist brought into the rope during installation to leave the reeving system.

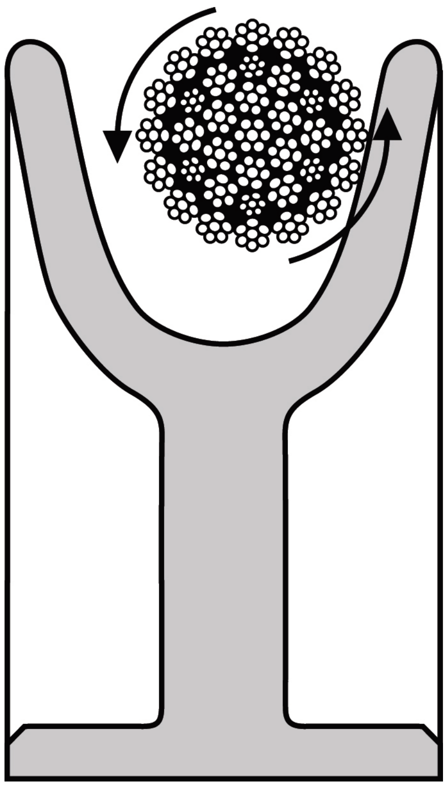

Figure 12: A steel wire rope entering a sheave under a fleet angle rolling down into the bottom of the groove

6. Conclusion

Obviously, the ropes of the three categories react very differently on the installation of a free spinning swivel. When attached to a non rotation resistant or to a semi rotation resistant rope, the swivel will at first sight cure an obvious problem (the rotation of the load), but it will create a hidden, and possibly much more dangerous safety problem: the wire ropes will operate at a reduced design factor and will in addition fail from the inside out. They will suffer from tension-torsion fatigue and might produce birdcages. If slack rope occurs, they will tend to form kinks. Therefore ropes of these two groups may not be operated with a free spinning swivel.

A rotation resistant rope, on the other hand, will not be adversely affected by the installation of a free spinning swivel. On the contrary, the swivel will even improve the rope's performance. Therefore wire ropes grouped as "rotation resistant" may and even should be operated with a swivel.

7. Different swivel designs

The most commonly used swivel is the free spinning swivel. It is designed on the one hand to transmit the axial wire rope force with a reasonable design factor (which might vary in different countries), and on the other hand to transmit as little torque as possible for the whole load range. Figure 13 shows a typical example of a free spinning swivel as a stand-alone solution, Figure 14 shows a free spinning swivel as part of a wire rope end connection. As explained above, free spinning swivels should only be used with rotation resistant ropes.

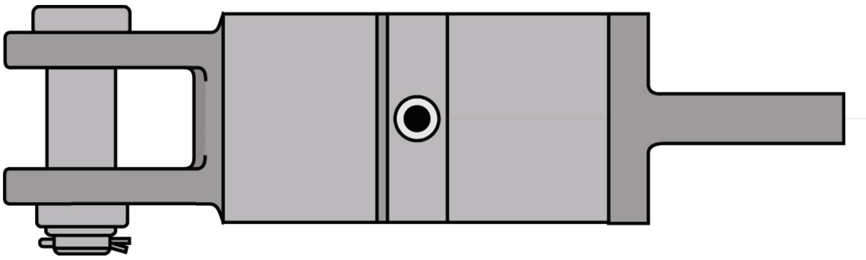

Figure 13: Free spinning swivel

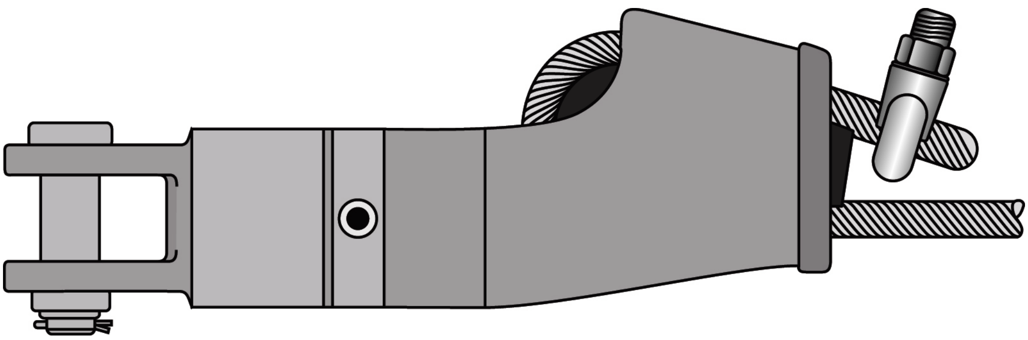

Figure 14: Free spinning swivel as part of an asymmetric wedge socket

Twist built-up in a reeving system often causes a hook block to rotate, especially in an unloaded state. This is because the rope has been twisted by the crane and now wants to regain its non-twisted state by twisting the hook block. Very often, the installation of a swivel will cure this problem by allowing the twist to leave the system. The more falls we have in a reeving system, however, the less effect the installation of a swivel will have: In a two part reeving, for example, the swivel will only make sure that the one fall between the wire rope end connection and the first sheave will always be free of twist. The other one might still be twisted (Figure 15). In an eight fall reeving (Figure 16), the swivel will have an even more limited effect: only 12.5% of all rope falls will be guaranteed to be free of twist. But even in an eight part reeving system the installation of the swivel might cure a twisting problem.

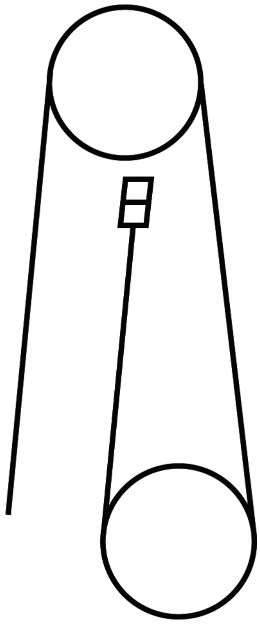

Figure 15: Two part reeving with a free-spinning swivel: 50% of the parts are guaranteed to be free of twist

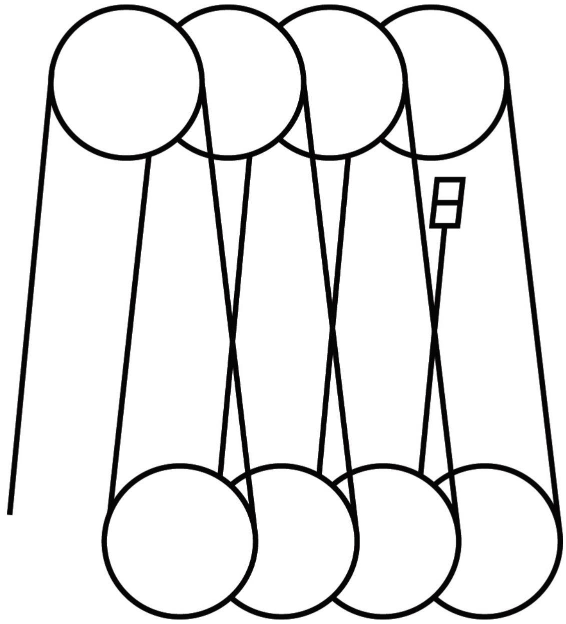

Figure 16: Eight part reeving with a free-spinning swivel: Only 12.5% of the parts are guaranteed to be free of twist

Unfortunately, we may only install a free spinning swivel with rotation resistant ropes. But would it not be helpful to have a mechanism to let out any twist built up in system via a swivel, also when non rotation resistant or semi rotation resistant ropes are used? Crane users have found a practical solution: They unload the rope and unbolt the end connection. The twist built up in the last fall of the rope will immediately disappear by twisting the end connection for a few turns. The end connection will then be put back in place. After a while, however, twist will have built up again and this procedure will have to be repeated.

The use of a lockable swivel or the use of a self-locking swivel will facilitate this procedure.

7.1 The lockable swivel

The lockable swivel is a free spinning swivel which may be locked by hand. In a locked condition, it will not be able to rotate. If twist has built up in the reeving system, the swivel can be unlocked, and a few trips up and down of the unloaded hook block will allow the wire rope to get rid of its twist by rotating the swivel. Afterwards the swivel is locked again. If the lockable swivel will only be used in an unlocked condition with low line pulls, it can be used in combination with non rotation resistant or semi rotation resistant ropes.

7.2 The self-locking swivel

The self-locking swivel is a more sophisticated version of a lockable swivel. It is designed so that it will operate like free spinning swivel up to a predefined level of line pull. If that level is exceeded, the two rotating halves of the self-locking swivel will interlock and prevent the swivel from rotating. A self-locking swivel may be used in combination with non rotation resistant, semi rotation resistant and rotation resistant ropes. Whenever the ropes are in an unloaded state, they can get rid of any twist built up in the reeving system by rotating the swivel. Whenever they are in a loaded state, however, they are prevented from unlaying because the swivel will be locked.

7.3 The powered swivel

As explained above, crane operators sometimes get rid of any twist in the last fall of their reeving system by unloading the rope, unbolting the end connection and letting the end connection swivel. Experienced rope engineers will then add one or two more turns to this rotation, they will literally “over-twist” the wire rope, before putting the end connection back in place. This will help neutralise part of the twist that has built up in the other falls and which would otherwise not disappear during this procedure.

A powered, or motorised swivel acts in a similar way: it is a swivel which can either act like a free spinning swivel but which can also, if required, actively twist the steel wire rope.

In a two part reeving system the swivel can only guarantee that the one fall between the wire rope end connection and the first sheave be free of twist. The other fall of the reeving system might still be twisted. In tower cranes with great lifting heights, however, this might not be sufficient to prevent the hook block from twisting. The answer to that problem might be a powered swivel, the prototype versions of which one of the authors (RV) has already successfully tested on very high tower cranes in Canada.

Let us suppose that the hoist rope of a tower crane operating with a two part block has built up twist. Each of the two hoist lines will try to twist the hook block with a moment of M+, and the resulting moment 2M+ will make the hook block rotate clockwise (Figure 17).

The installation of a free spinning swivel would immediately reduce the moment of the one of the two falls to zero (M_{zero}), but the other fall would still try to twist the hook block with a moment M+ (Figure 18). The hook block would still twist, but to a lesser degree.

The installation of a powered, or motorised swivel would at first have the same result: the swivel would free-spin and reduce the moment of the one of the two falls to zero (M_{zero}), but the other fall would still try to twist the hook block with a moment M+. Now the crane operator would activate the motor of the powered swivel and slightly “over-twist” the rope part attached to the swivel until the block is no longer twisted. In this situation a moment M+ would act, for example, clockwise on the one side, and a moment M- of the same magnitude would act anti-clockwise on the other side (Figure 19). The resulting moment on the hook block is zero (M_{zero}). As soon as the operator would start operating the crane, rope zones twisted in a positive sense and rope zones twisted in a negative sense would come together and the twists would neutralise each other. As a result, the moments M+ and M- would quickly disappear. Because of this effect it is a characteristic feature of the powered swivel that it must only be activated on rare occasions.

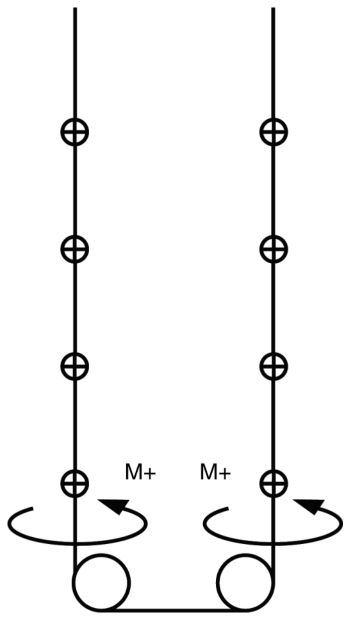

Figure 17: Two part reeving without swivel: The moments of the two twisted parts add up: M+ + M+ = 2 M+

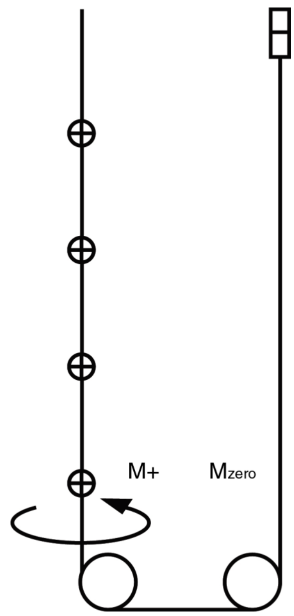

Figure 18: Two part reeving with a swivel: The resulting moment is considerably reduced by the swivel: M+ + M_{zero} = M+

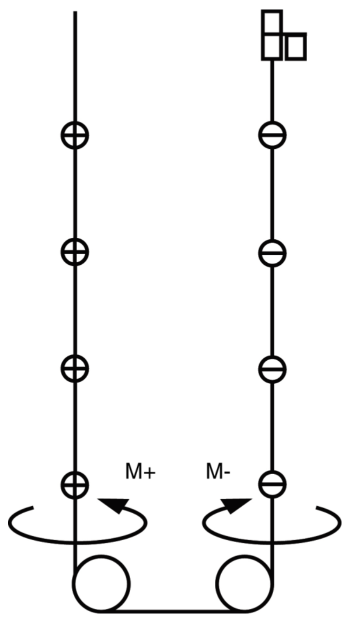

Figure 19: Two part reeving with a motorised swivel: The moments of the two parts act in opposite directions and neutralise each other. The resulting moment is zero: M+ + M- = 0

8. Final comment

Free spinning swivels are relatively common. A great percentage of them, however, is incorrectly used. Lockable, self-locking and motorised swivels, on the other hand, are not easily available on the market. An internationally accepted terminology classifying wire ropes with respect to their rotation characteristics and clear guidelines will hopefully end the confusion about how and when to use a swivel.

9. References

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