WORKING GROUP D
ROPE ATTACHMENTS
Reporter: G. Oplatka - ZUERICH

1. Reason for development

Most rope end connections, including those between the carriers of aerial tramways and haul ropes, have to satisfy high demands. Although subjected to alternating stress and weathering, they are expected to transmit the rope forces involved for years or even decades on end without weakening. The conventional type of connection used for such purposes is the cast socket, for the production of which a good deal of care is necessary. If, for instance, all traces of the pickling agent used for cleaning the wires' ends are not removed, water may seep in and cause internal corrosion. Since wire failure and corrosion within and at the socket entry cannot be reliably detected, the cast socket is not dependable enough. This has been demonstrated by recent accidents.

Attaching of the rope ends by the use of anchoring drums is only possible where there is adequate accommodation for the large and heavy drums required.

Consequently it was decided to develop a rope end connection that was not only reliable and easy to make and check, but which was of about the same size as the cast socket and could thus be easily exchanged.

Extensive theoretical work and testing led finally to the clamp-type socket described below.

2. Description of clamp socket (Fig. 1)

The strands at the end of the rope are untwined and straightened so as to lie along the surface of an imaginary cone (Fig. 2). The core of the rope is appropriately shortened. The strands of the rope are then clamped between the tapered outer sleeve (2) and the inner cone (3). The length of the inner cone, and therefore also the clamping length, is seven times that of the rope diameter. The angle of taper of 10° has been selected because it proves to be self-locking. To reduce local surface pressures and as a result also compressive stress in the wires both cone and tapered sleeve are lined with a malleable aluminium wire (MB = 0.5 kN/mm²). The wires of the strands can thus embed themselves in the aluminium. In this way a larger area of contact is achieved and the local surface pressures are restricted to the yielding point of the lining material (Fig. 3).

*) Swiss Federal Institute of Technology Zurich, Switzerland
The inner cone is pointed at the tapered end, so that the pressure on the strands can gradually increase. At the wide end of the cone is the cone holder (5). This component has a dual function: apart from connecting the cone (3) with the strands during the assembly stage, so that these can be accurately positioned (Fig. 4), it also makes safe the start of the clamping action. For the strands to be clamped between the taper sleeve (2) and the cone (3), when the load on the rope increases, the cone (3) must be pulled into the sleeve in the direction of the rope. When the load on the rope is 0 the clamping action is undefined. To “start off” the clamping action an initial force has to be exerted upon the cone (3). As shown in Fig. 1, this force is transmitted to the cone via the cone holder (5). In order to ensure a smooth deflection of the strands from their position in the rope to the conical form, the mouth of the clamp socket is provided with a deflection sleeve (6). A length of sleeve double the rope diameter suffices to give an adequate pulsating tensile strength. Lengthened to five times the rope diameter, this sleeve also functions as a protective sheath and keeps the alternating bending stress away from the clamping zone. The hollow spaces within the socket are kept full of grease, which is introduced via a grease nipple in the attaching fork (7). Apart from increasing the alternating bending strength of the wires throughout the transitional zone, the grease prevents moisture from entering the clamp socket and thus protects the device from corrosion. In the event of dirt or moisture entering the clamp socket from the rope end, these are forced out again when the next lot of grease is applied through the nipple.

3. Testing of clamp socket

The safety, dependability and limitations of the clamp socket have been demonstrated by extensive testing. Apart from demonstrating the holding force of the connection, i.e. that the strands cannot slip out of the clamp socket, the tests also showed it to possess satisfactory long-term behaviour (fatigue strength). Two different Seale-type ropes (diam. 18 and 28 mm) with breaking forces of 200 and 500 kN were used, for which special testing machines were also required (1).

3.1 Testing holding force of clamp socket

3.1.1 Static tensile tests. Although the rope strands broke most frequently in the deflection zone of the socket, the ropes displayed each time the breaking strength guaranteed by the producer. This was also the case when, in order to test for the effects of an initial non-uniform load distribution, the strands were affixed with lengths differing by as much as the diameter of the strand.

3.1.2 Endurance tests. Since the aluminium wire lapping was subjected locally to a stress higher than its yielding point, the question was whether and when the initial creep of the strands would stop. Tests showed that this occurred after 50 hours at a tensile force of 20 % of the breaking force and after less than 700 hours at a force of 75 %.

3.1.3 Tensile impact test. In this test the clamp socket was subjected first to a force equal to 20 % of the breaking force. Then the cone holder was removed and the socket subjected to a sudden tensile impact created
by a falling weight. This was to test the efficiency of the clamp socket during sudden increases in the tensile force. Although the impact forces applied were equal to 60 to 70% of the breaking force, the clamp socket withstood the forces in each case.

3.1.4 Sudden-load-relief test. If rope tension is suddenly relieved, either completely or partly, a shock wave travels back to the end of the rope. This could lead to a loosening of the inner cone and cause the strands to slip when the rope tension increases again. To check for this possibility three tests were carried out. The clamp socket and rope were loaded as in the static tensile test. The other end of the rope was fixed to a connection designed to fail at 20, 40 and 60% of the breaking force, thus causing a sudden relief of tension. Although the clamp socket was tested without the cone holder, there was no loosening of the strands during any of the tests.

3.1.5 Testing dynamic holding force of socket. According to Prof. O. Zweifel [2], if the angle of taper is too large a greater load change amplitude could cause the strands to work their way gradually out of the connection despite the static self-locking action. (In the case of clamp sockets with larger angles of taper and different linings this phenomenon has in fact been observed.) Consequently, where the stress to which the rope is subjected is not predominantly static the clamp socket must be tested for its holding force under pulsating stress. In all the pulsating tensile tests the cone holder was removed after the clamp socket had been subjected to an initial load. A pulsating tensile force was ranging from 0 to a maximum of 0.66 kN/mm². No loosening of the strands or of the cone was observed, which indicates that the angle of taper of 100° is adequately small.

3.1.6 Torsion. Depending on the installation, the torsional moments acting on the rope end connections can be greater than it might be expected in function of the rope construction and its tensioning force. Therefore, the behaviour of the clamp socket in case of twist congestion or twist relief of the rope has been investigated. During these tests the rope tensioning force amounted to 10 - 30% of the breaking force. The tests showed that, in order to produce a torsional slip in the clamp socket, the torsional moment applied on the rope must be 5 - 8 times greater than it might be expected in function of the rope construction and its tensioning force. However, such torsional moments cause a very strong permanent deformation of the rope and may scarcely be found in practice. In no case the strands moved outward in the clamp socket in a dangerous way.

3.1.7 Influence of heat. Tests had to be made to find out whether high temperatures and the difference in temperature occurring between the outer sleeve and the inner cone in case of rapid heating have an effect on the creep behaviour of the clamp socket. The rope was loaded with a tensioning force pulsating between 6 and 20% of the breaking force. At the same time the clamp socket was rapidly heated to the given temperature from outside; it was kept at this temperature for a certain time and then slowly cooled down. After approx. 30 repetitions of this procedure the upper limit of the temperature was gradually raised up to 180°C.
After each raising of the upper limit of the temperature a small settle movement of the rope took place. When the temperature was raised to the same level repeatedly, the amount of settle movement decreased asymptotically towards zero.

3.2 Fatigue tests

3.2.1 Pulsating tensile test. Subjected to a pulsating tensile force kept within the limits usual for ropeway haul ropes (10 to 26 ° of breaking strength) and with load changes of up to $4 \times 10^6$, only isolated wire breakages occurred both in the deflection zone of the clamp socket and in the free part of the rope. With large widths of swing the part of the rope within the socket proved more durable than the free part. This is due to two reasons: under heavier loading the plastic core of the rope is compressed to a higher degree and the wire strands are subjected to pressure and rubbing; secondly, as a result of the shape of the inner cone and the use of the malleable wire lapping the strands are kept firmly in position without the possibility of kinking, while at the same time being allowed to assume an optimum referring to stress within the deflection zone when the rope is subjected to loading.

3.2.2 Alternating bending tests. As a result of the rope oscillations the wires are subjected, especially at their point of attachment, to alternating bending stresses. To test them for alternating bending strength the ropes were tensioned by applying a load equal to 20 ° of the breaking force and the clamp socket was bent to and fro through an angle of ± 4,5 °, which is the maximum value observed in ropeway operation (3). After $4 \times 10^6$ oscillations the clamp sockets displayed no wire breaks. Similar testing of cast sockets resulted in an average of 36 wire breaks per test.

3.2.3 Pulsating tensile and alternating bending tests. Here the rope end connections were subjected to previously described stresses (a pulsating tensile force pulsating between 10 and 26 ° of the breaking force and to alternating bending by deflection of the clamp socket through ± 4,5 °). For every pulsation of the tensile force the clamp socket was subjected to 4,8 alternating bendings, which corresponds roughly to the conditions obtaining in an aerial tramway with 4 towers. On an average the clamp sockets stood up to $1,6 \times 10^6$ alternating bending stresses, or double the life of the cast sockets. Worthy of note is the fact that the wires began to break earlier in the case of the clamp socket, in relation, that is, to the total length of life, which means that the clamp socket gives warning of failure relatively early and thus ensures increased safety.

3.2.4 Corrosion tests. The aim of these tests was to check the corrosion strength of the clamp socket and to find out possible weak spots. In order to permit an optimal action of corrosion during the test, the rope was
- vertically suspended with the clamp socket looking downwards,
- slightly tensioned and stressed with alternating torsion,
- periodically sprayed with salt water.
A DC potential was set between the rope and the outer sleeve.
The tests were carried out until the breakage of the rope, which always
occurred in the free part of the rope. In no case corrosion was found within the clamp socket.

However, an infiltration of water to the top of the inner cone via the core is possible. To remove this water a regular relubrication of the clamp socket is necessary.

It has again been confirmed that, when there is corrosion, the time interval between the appearance of the first wire breakages and the collapse of the stressed rope is very small.

3.3 Practical experiences

The first clamp socket was put to work in 1975 at a materials aerial tramway which has been very frequently used. A year later the first public installations were permitted to be equipped. As far as we know, at least 265 clamp sockets were in operation at the end of 1982.

On the occasion of the annual inspection no wire breakage or corrosion has been observed until now, therefore, the intervals of controls could be extended to two years. Experience will show whether a further prolongation will be possible and recommendable.

The control of a clamp socket (taking apart, checking, assembling) takes approximately one hour. Since the clamp socket (in contrast to the cast socket) can be assembled in any position and the rope has not to be straightened for a longer stretch, the termination is substantially easier. It is sufficient to unload the rope just as much that the attaching bolt can be removed, which may be done with the aid of hydraulic cylinders. It is not necessary to install pulley blocks with long ways.

4. Summary

A new rope end connection has been introduced, a so-called clamp socket, in which the individual wire strands are held fast by the self-locking action of an inner cone and outer taper sleeve. To avoid extreme local surface pressures both the inside of the sleeve and the outside of the cone are lined with a malleable material (aluminium wire). The rope oscillations are prevented from affecting the clamping zone by a plastic deflection sleeve. The hollow spaces within the socket are filled with grease. Static and dynamic tests showed the clamp socket to be just as good, if not better than the cast socket. In contrast to the cast socket the clamp socket can be easily taken apart, checked and, if still serviceable, re-used. The external measurements of the clamp socket are roughly the same as those of the cast socket, which means that they can be fitted in place of these on installations already in use.

The altogether positive test results and practical experiences can be attributed to the following circumstances:

- Thanks to the malleable lining, the strands cannot be influenced by any forces greater than those which are limited by the yielding point of the lining material.
During the first tensile loading of the rope the strands can move axially as well as tangentially in a limited way. In doing so, they are able to assume an optimal position referring to stress. This means that finally all of them are equally loaded and possible bending stresses will be reduced or cannot occur at all.

The entrance of water as well as of oxygen being barred, there is no danger of corrosion. If, for instance, the wick-effect of the core would cause an infiltration of water after all, the latter would be removed again on the occasion of the periodical relubrication. As an electrically negative element, the aluminium lining is additionally protecting the steel wires from corrosion.

5. Warning

In spite of the simplicity of the design we must, for security reasons, express an urgent warning to any person who might consider designing the clamp socket on the basis of this report or assembling it without possessing a user's manual or having attended the relevant courses.
Literature:

(1) Oplatka G. and Siebenhaler H.:  
Fatigue Testing of Rope End Connections.  
International Aerial Tramway Review 1975, Number 5.

(2) Zweifel O.:  
Theorie zum Klemmnapf für Litzenseilbefestigung.  

(3) Oplatka G. and Roth M.:  
Wire Breakages in Haul Ropes in the Neighbourhood of Couplings.  
International Aerial Tramway Review 1974, Number 4.

(4) Oplatka G. and Roth M.:  
Equipment for investigating wire ropes used by the Institute  
for Construction Equipment and Transportation Machinery,  
Swiss Federal Institute of Technology Zurich.  
Fig. 1: Within the clamp socket the individual rope strands (1) are held tight by the self-locking action of the tapered outer sleeve (2) and the inner cone (3). To avoid extreme local surface pressures, the outside of the cone and inside of the sleeve are lined with malleable material (4). The cone holder (5) triggers off the self-locking action when the initial load is applied. The sleeve (6) keeps the rope vibrations away from the clamping zone. The hollow spaces within the socket are filled with grease introduced via the nipple on the attaching fork (7).
For the assembly of the clamp socket the strands at the end of the rope are untwisted and straightened. This is what the rope end looks like when the socket is dismantled. It can be checked and if still in good condition reassembled.
Fig. 4: Once the inner cone has been pushed in between the strands and affixed to the cone holder, aluminium wire is wound round the strands.
Fig. 3: Inner cone after socket has been subjected to pulsating tensile test. The marks show where the strands embedded themselves in the aluminium wire lapping. Local surface pressures are restricted to the yield point of the lapping material.