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A new and innovative wire rope bending fatigue machine

Abstract

In conventional bending fatigue machines, a relatively short section of the test rope travels over one test sheave only. Many effects found in typical rope applications cannot be reproduced by these fatigue machines. This paper describes a new concept for a bending fatigue test machine which can produce conditions typically found on a crane. The machine subjects different sections of the test rope to different numbers of bending cycles. Measurements during the test and an analysis of the different rope sections after the test lead to a wealth of information about the rope and its degradation mechanism. Some preliminary results from work undertaken for NASA are presented in the paper.

1 Conventional bending fatigue machines

In a conventional bending fatigue machine a steel wire rope travels back and forth over a single test sheave (Figure 1).

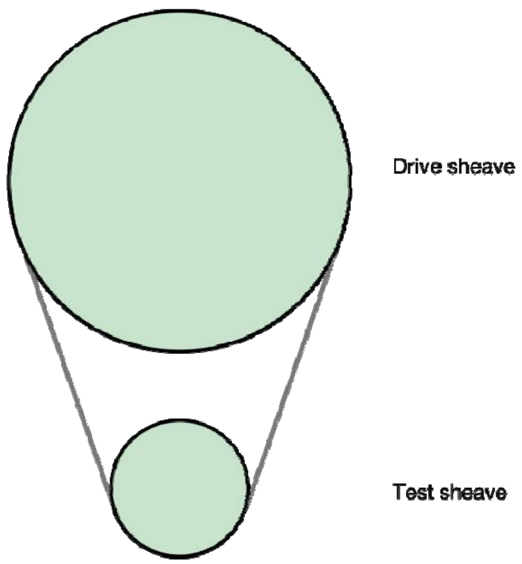

Figure 1: Conventional bending fatigue machine.

The rope is hereby subjected to two bending cycles in the middle section A of the test length, while two sections B on both sides of the middle section are subjected to one bending cycle only (Figure 2). This is because these rope sections only travel onto the sheave and off again. The length of the sections B corresponds with the contact arc of the rope on the sheave, the length of section A is the stroke minus the length B.

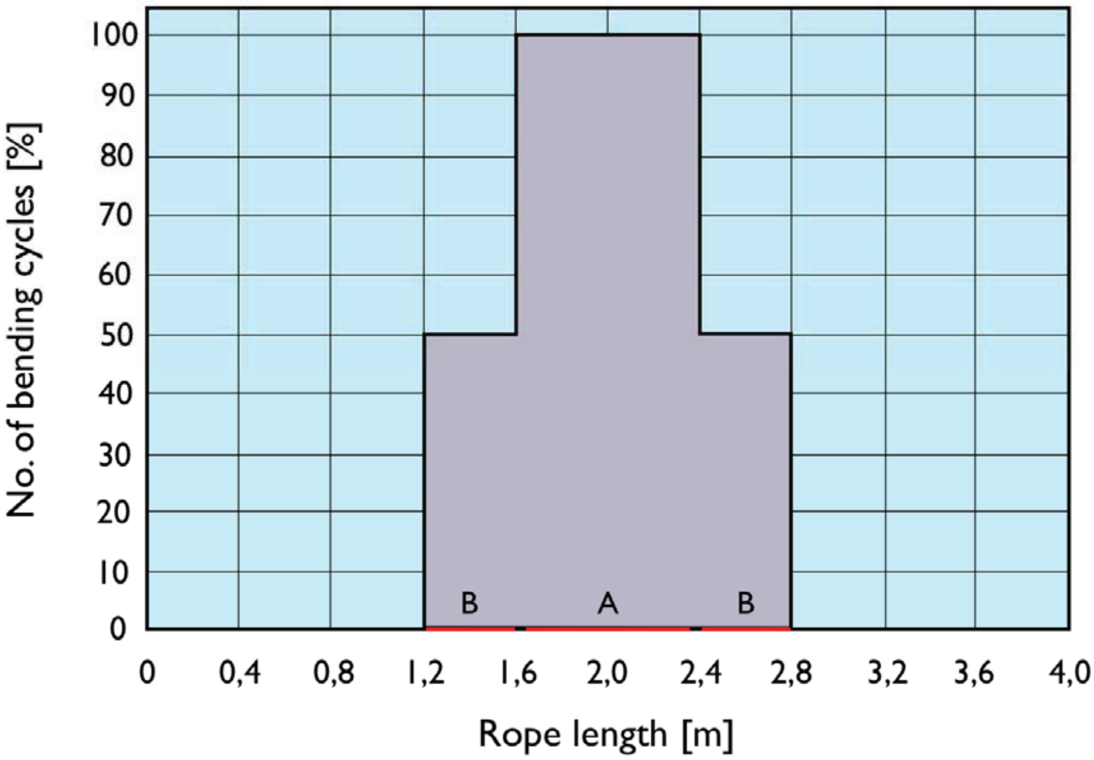

Figure 2: Bending cycle distribution in a conventional fatigue machine.

One problem of such a conventional bending fatigue machine is that its stroke is relatively short, resulting in a very short test section A. Especially when sheaves with large D/d- ratios are used, it might even be difficult to obtain a representative test length of 30 × d.

Another, much more important problem, however, is the fact that many imperfections of the test rope will not be detected by such a machine. If, e.g. during the rope production an incorrect backtwist has been used, the wires of the outer strands of the rope might have come loose. In a field application such a rope will have a very poor performance, but on the test machine it will still perform well: the test sheave will milk the looseness out of the test zone and from then on the test will continue with a good rope.

Figure 3 shows another version of this conventional bending fatigue machine.

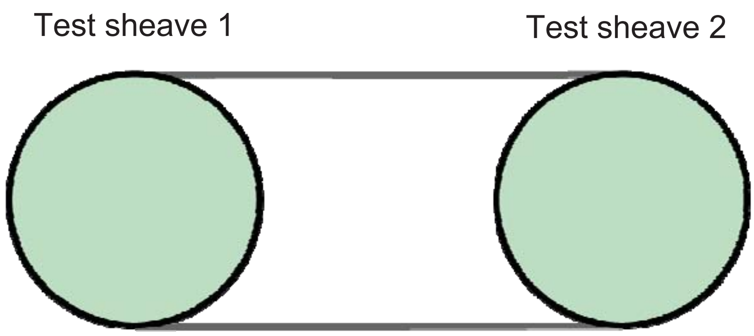

Figure 3: Conventional bending fatigue machine with two test sheaves and a closed rope loop.

Machines of this design have all the disadvantages mentioned above plus an additional problem: the heat generated by bending the rope can only dissipate via the test sheaves. The rope itself cannot conduct the heat along its length to cooler areas of the machine (as this would normally occur e.g. on a crane) because the other side of the machine develops the same amount of heat. In these test machines a great heat built-up in the ropes can be observed.

This enormous temperature increase, however, is not a rope related problem, it is mainly a problem of the test machine design.

2 Description of the new type of test machines

The new type of test machines presented here has a greater number of test sheaves like in a typical a reeving system of a crane. The sheaves are arranged in a way that the rope can travel through the reeving system without being subjected to any fleet angle (Figures 4a and 4b).

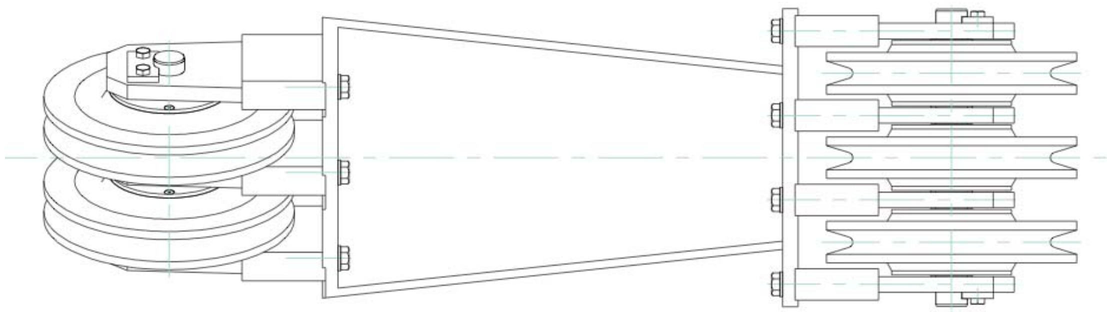

Figure 4a: Sheave arrangement of the test machine.

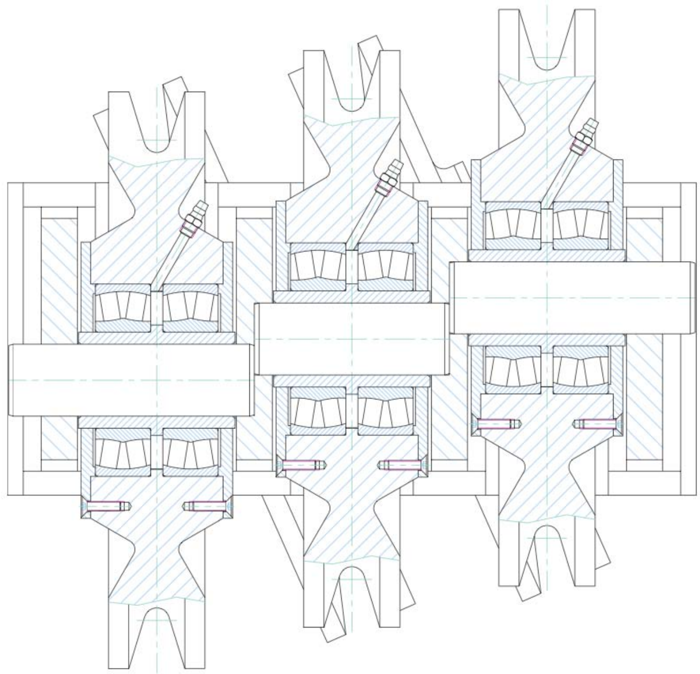

Figure 4b: Sheave arrangement of the test machine.

Figure 5 shows a schematic view of a test machine for ropes up to 10mm. The authors have built this machine as a prototype.

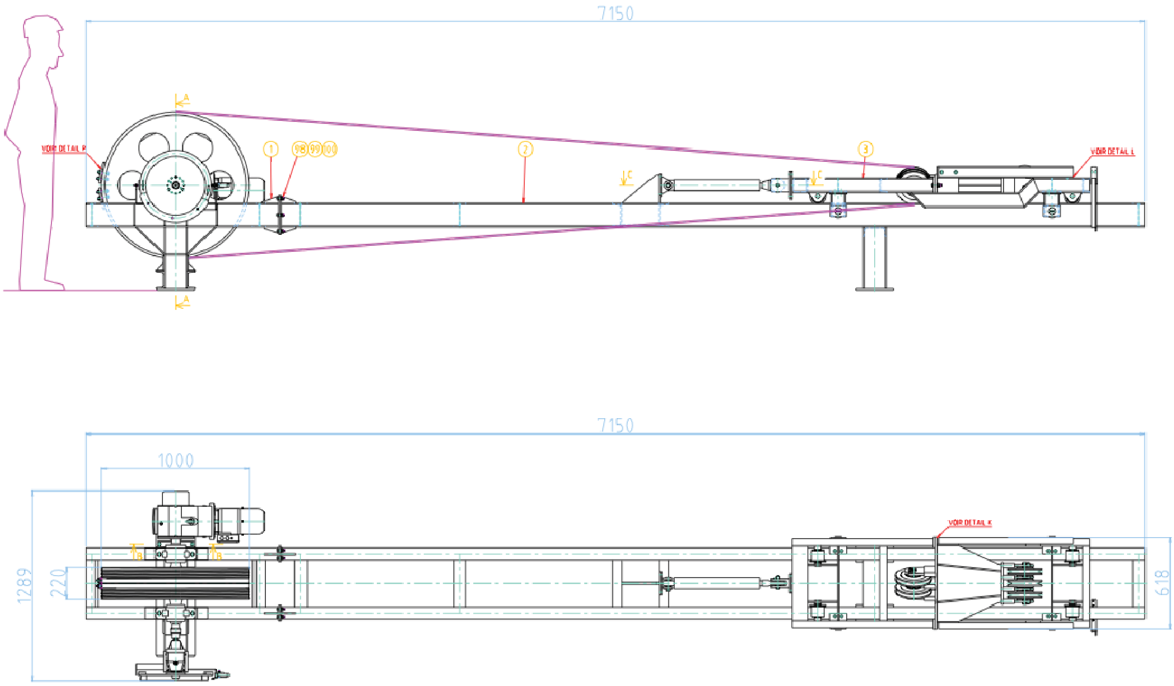

Figure 5: Small bending fatigue machine (rope diameter up to 10mm).

Figures 6, 7 and 8 show a similar test machine for ropes up to 30 mm in diameter. Two test machine of this design have been produced and sold as of this date.

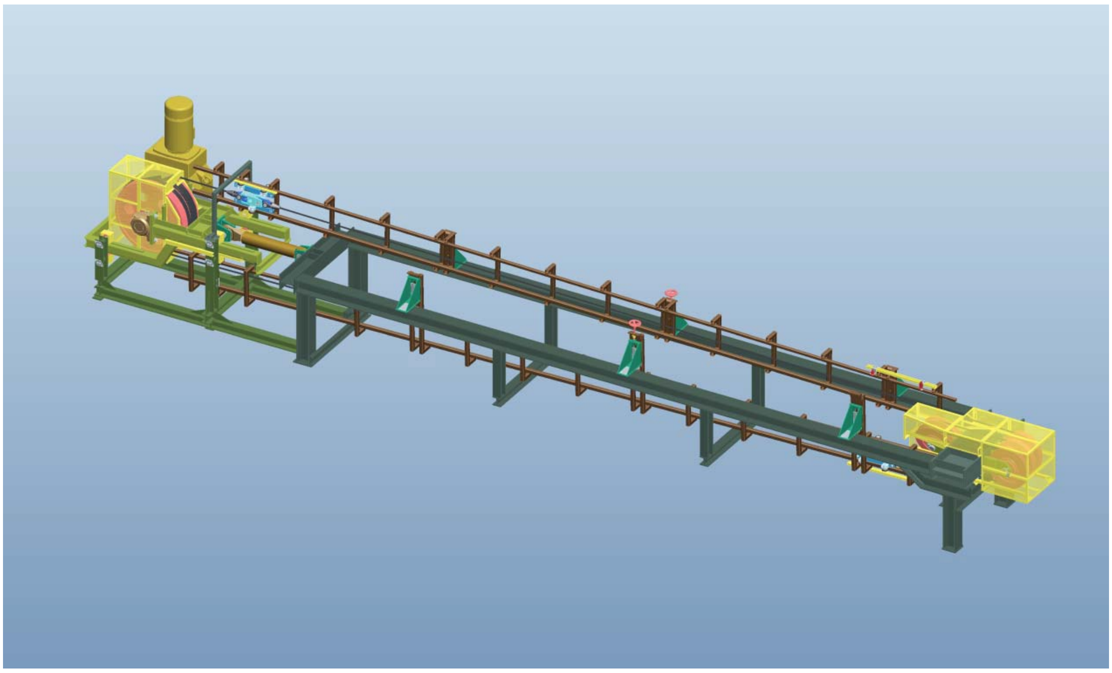

Figure 6: Test machine for ropes up to 30 mm diameter.

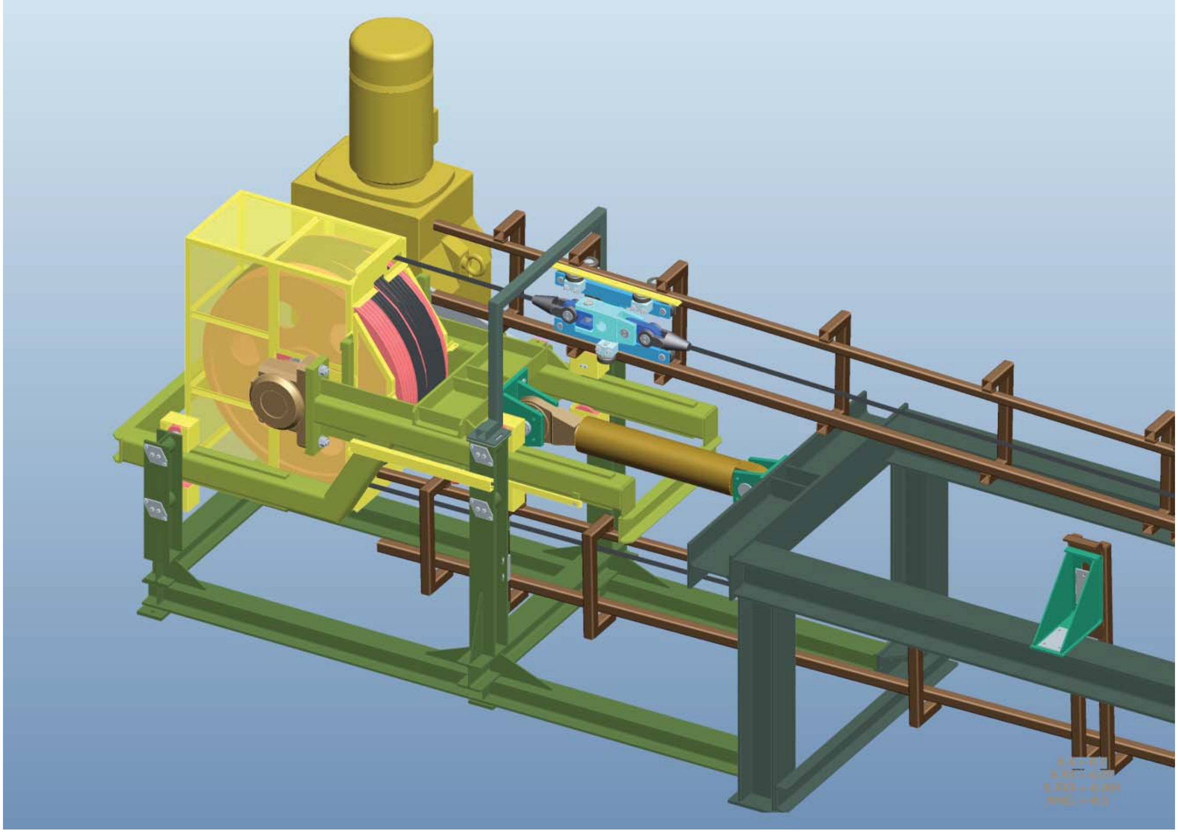

Figure 7: Drive unit with double drum and rope tensioning cylinder.

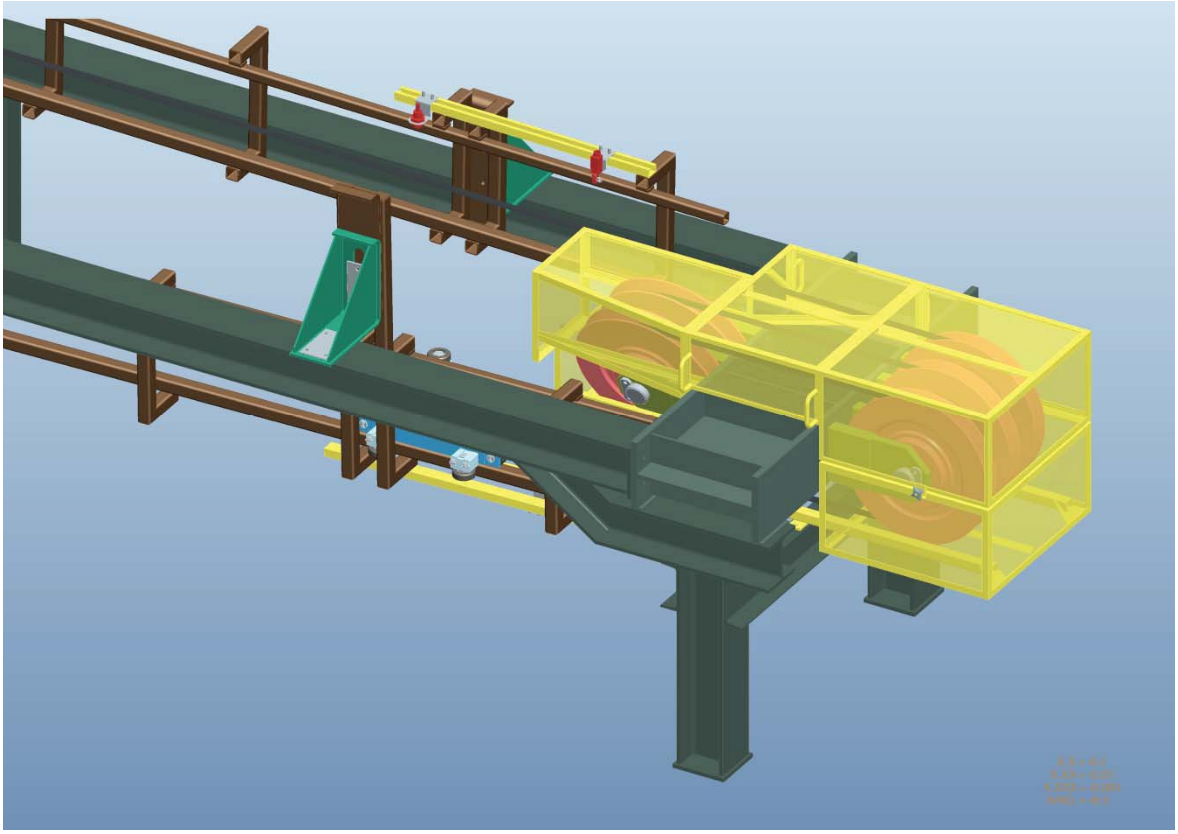

Figure 8: Test sheave arrangement.

In the bending fatigue machines of the new design a rope is reeved from a drum (Figure 6 left and Figure 7) through a sheave system with e.g. 5 sheaves (Figure 6 right and Figure 8) and back to the drum.

During a full machine cycle the most stressed rope section in the middle of the test rope travels back and forth over 5 sheaves, subjecting the rope to 10 bending cycles (Figure 9). In this section, the length of which can be influenced by the stroke of the machine, the rope will eventually fail.

To the left and to the right of the most stressed rope zone we find rope sections which will travel over 4, 3, 2 and 1 sheave only, subjecting the rope to 80%, 60%, 40% and 20% of the bending cycles of the most stressed rope zone.

The length of these zones can be influenced by the distance of the sheaves in the machine.

For normal testing, hardened steel sheaves are used. But of course also sheaves made of other materials such as polyamide or cast steel can be installed.

The test machine is equipped with a device that detects the first wire breaks. The machine stops automatically when the rope breaks.

3 The advantages of the new design

Compared to the conventional bending fatigue machines, the new design has a great number of advantages:

Once the test rope has been installed in the machine, the test can run without interruption until the wire rope or fibre rope fails in the middle in the rope section where the greatest number of bending cycles have occurred.

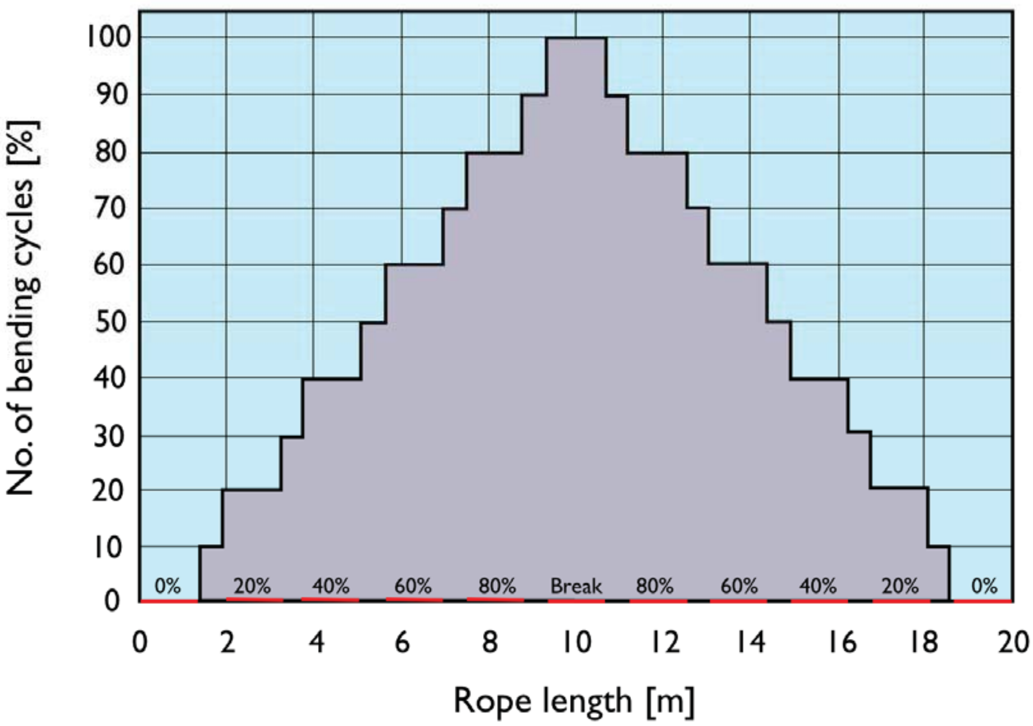

Figure 9: Distribution of bending cycles along the length of the test rope.

A “milking” of loose rope elements will not happen because the neighbouring sheaves will not allow this material displacement. Unlike with conventional machines, a rope with a design or production defect will therefore achieve a bad test result, drawing attention to the problem.

After the test, the rope sections which have been subjected to 100%, 80%, 60%, 40%, 20% and 0% of the number of cycles until break can be cut out and analyzed separately.

There will be one section with 100% of the cycles to failure only, but two for every other percentage. One of these two sections could be used to determine the evolution of the visible wire breaks on the rope surface with increasing number of cycles.

After these investigations the rope samples which had been subjected to 80%, 60%, 40%, 20% and 0% of the number of cycles until break can be subjected to a break test in order to determine the change in breaking strength during the rope life.

4 Preliminary results

The first bending fatigue test on the prototype machine was carried out for NASA. In the clean room environment of the Space Station processing facility (Figure 10) NASA uses ropes without any lubricant. The purpose of the test series was to determine whether the existing discard criteria for steel wire ropes can also be applied to these “dry” ropes.

Figure 10: The 30t overhead crane in the NASA Space Station facility.

The rope sections subjected to 0%, 20%, 40% 60% and 80% of the bending cycles to failure showed an increasing degree of internal fretting corrosion which became highly visible after the break test of the different rope sections.

Figure 11 shows the test specimens which had been subjected to 0% (bottom), 20%, 40%, 60% and 80% (top) of the bending cycles to failure after break testing. It is obvious that the corrosion increases with increasing number of bending cycles.

Figure 11: Rope sections which had been subjected to 0% (bottom), 20%, 40%, 60% and 80% (top) of the bending cycles to failure after break testing.

Figure 12 shows the evolution of the breaking strength of the non-lubricated steel wire rope tested for NASA. At 80% of the number of cycles to failure the rope still has a higher breaking strength than when it was new.

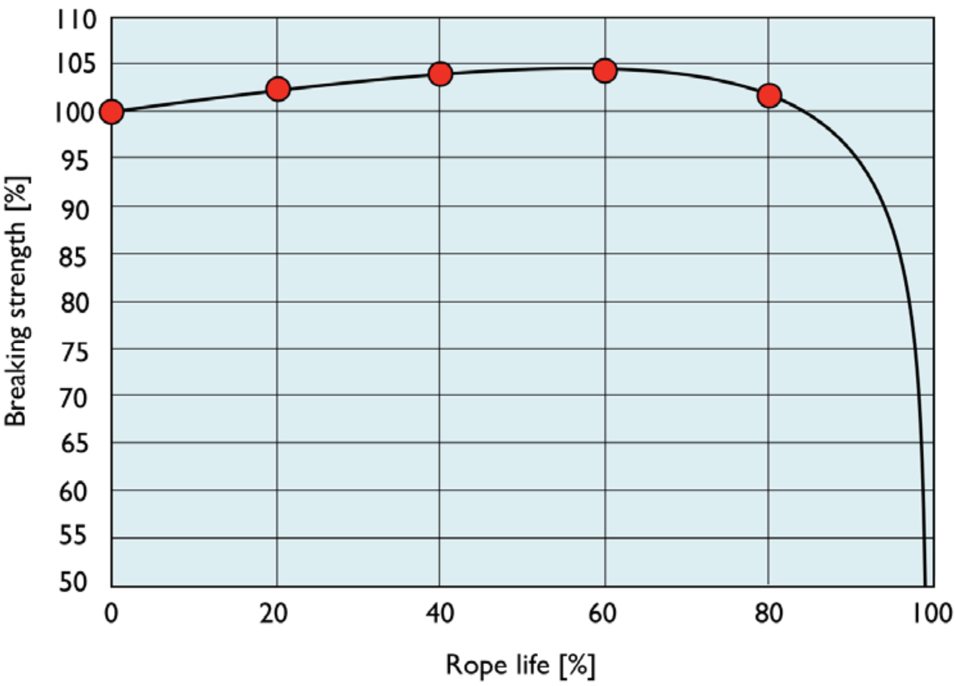

Figure 12: Evolution of the breaking strength of a non-lubricated steel wire rope. At 80% of the number of cycles to failure the rope still has a higher breaking strength than when it was new.

The rope sections on both sides can also be used to determine the evolution of the wear ellipses on the outer strands without destroying the specimens.

As an example, Figures 13 and 14 show the wear ellipses of a steel wire rope tested without lubricant for NASA after 20% and 40% of the number of bending cycles to rope failure.

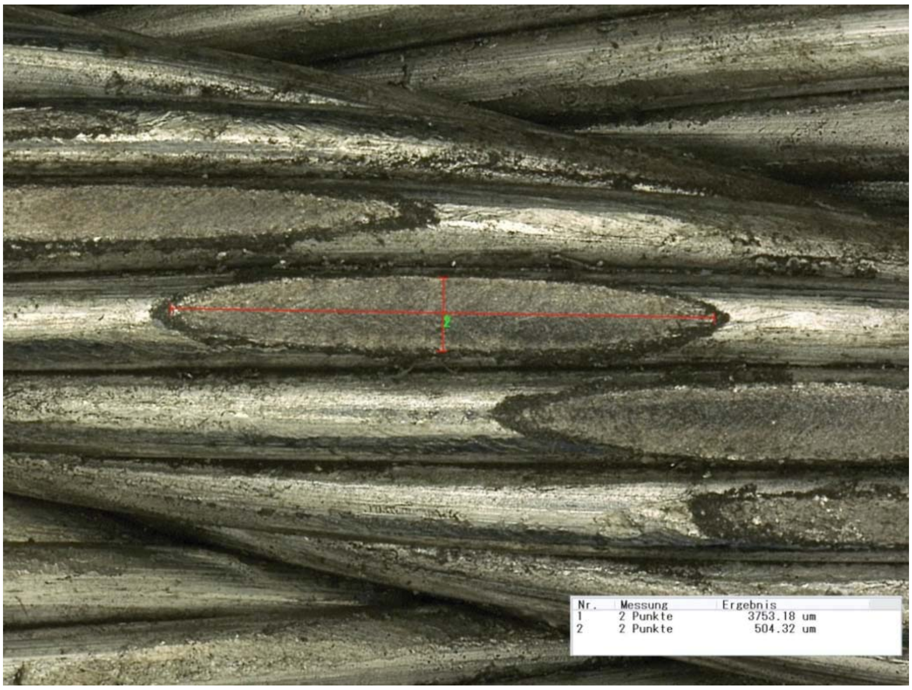

Figure 13: Wear ellipse of a steel wire rope tested without lubricant after 20% of the number of bending cycles to failure.

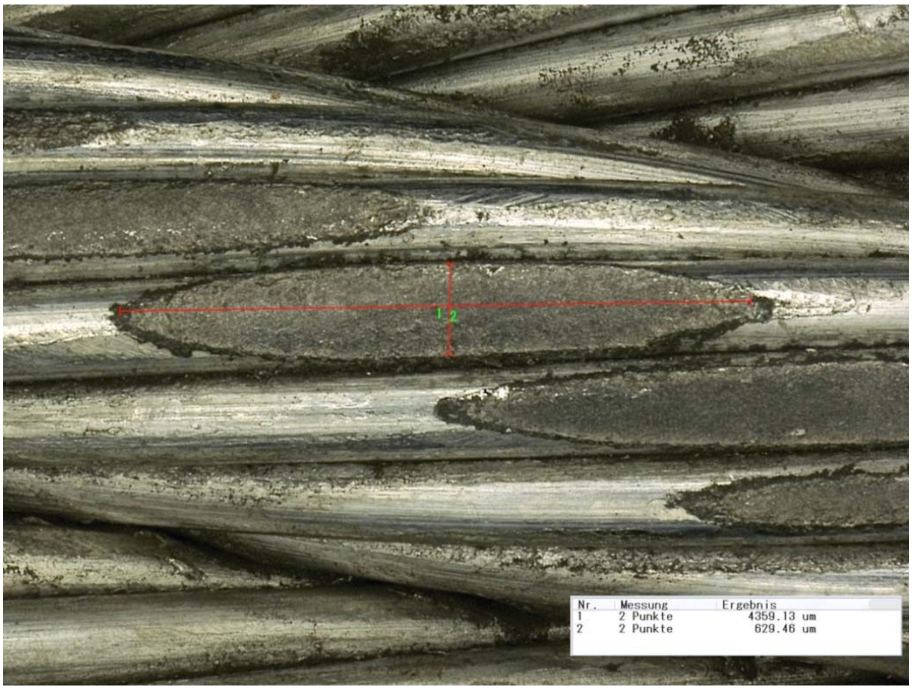

Figure 14: Wear ellipse of a steel wire rope tested without lubricant after 40% of the number of bending cycles to failure.

Based on these measurements, a curve of the evolution of the ellipse dimensions over the rope life can be plotted (Figure 15). These dimensions might serve as additional discard criteria.

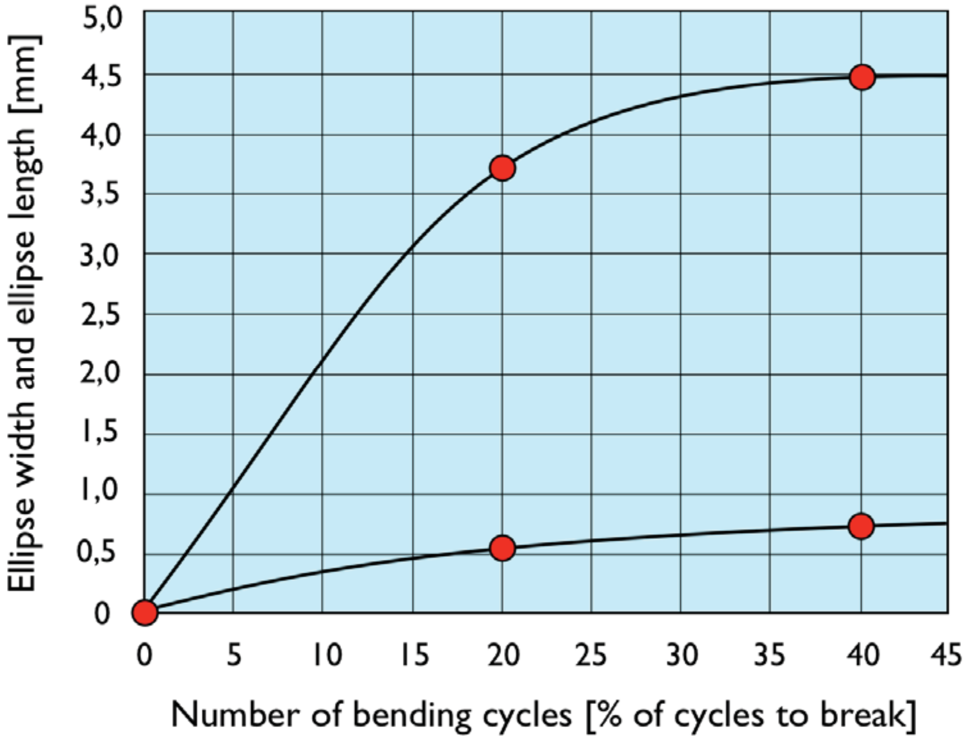

Figure 15: Evolution of the wear ellipse length (top curve) and width (bottom curve) over the rope life.

In a similar manner, the evolution of internal rope defects can be determined after the bending fatigue test by dissecting the rope sections of 100%, 80%, 60%, 40%, 20% and 0% of the number of cycles until rope failure.

If, e.g. the analysis of the break section of the bending fatigue test shows that the rope has a great number of internal wire breaks, an analysis of the other rope sections will show how these defects developed with increasing number of bending cycles.

This information can be very helpful for a rope user because it will give him a correlation between the number of internal (non visible) and external (visible) wire breaks.

The same information will help a rope designer to change the rope geometry in a way that it will improve the conditions of those rope elements which in the test failed first.

In a conventional bending fatigue machine, at least 9 tests would have to be carried out and stopped at the respective number of cycles in order to take the rope apart. In the machine presented here the same information can be determined in one single test.

During the first tests with the machines presented here, the rope temperatures were constantly measured. They never exceeded 48°C.

A load cell installed between the rope on the drum and the test rope (see Figure 7) allows for a continuous or discontinuous measurement of the steel wire rope efficiency. When the rope travels back and forth over e.g. 5 sheaves, the static line pull plus or minus the friction loss on five sheaves can be measured. From these data the rope efficiency to the fifth power and the rope efficiency itself can be determined with great accuracy.

Because the load measurement can be done throughout the entire duration of the test until rope failure, the change of the rope efficiency over the lifetime of a rope can be continuously measured. According to the opinion of the authors, such an analysis has never been carried out before.

Similar tests with different D/d ratios and different line pulls allow to analyze the influence of these parameters on the bending fatigue life, the evolution of the rope breaking strength, of abrasion, external and internal wire breaks, on rope efficiency as well as heat generation.

5 Summary

The new and innovative bending fatigue machine avoids the main disadvantages of conventional test machines. It allows to perform bending fatigue tests under realistic conditions and to accumulate a wealth of information about the tested rope with only very limited number of tests.

The fatigue test will be run without any stop until the rope fails. Different rope characteristics such as the rope efficiency can be measured continuously or discontinuously during the test.

Then sections to the left and to the right of the failure point will be used to determine the evolution of the rope damage. The external damage can be analyzed on both sides. The internal damage can be analyzed by dismantling rope sections which have been subjected to 0%, 20%, 40%, 60% and 80% of the number of cycles to rope failure. The equivalent section from the other side can be subjected to a break test.

6 Acknowledgements

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