HARVESTING TECHNICAL NOTE

HTN05-11
2013

Tension Monitoring of a Cable Assisted Machine

Summary

The mechanisation of felling and bunching for subsequent extraction by cable yarders can increase productivity significantly. Cable assisted steep terrain harvesting provides an opportunity to improve safety as well as productivity. The task of felling is associated with the greatest safety risk if carried out manually. Two cable assisted systems have been developed and tested in New Zealand – a system developed by contractor Ross Wood, and the Trinder ClimbMAX steep slope harvester. In both these systems a good operating knowledge of the tension in the tethering cable is important for operating safely on steep slopes. This study examined these systems and the basics of the slope tension relationship, and reports on actual cable tensions measured from Ross Wood's operation. For the majority of normal operating conditions associated with travel, felling and shovelling, the cable tensions were well within the safe working load (SWL) of the cable. However in the more extreme tests, such as full winch power with tracks locked, the tensions did reach SWL. Shock and cyclic loading were also recorded. Results indicated that the system is safe to operate, but care should be taken to avoid situations where tensions can approach safe working load.

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INTRODUCTION

Ground-based operations are typically more cost-effective for harvesting timber in than either cable or aerial extraction systems. As such, there are benefits to extending their safe operating range. Cable assisted (also known as tethered) machinery is a relatively new development in New Zealand forest operations to help ground-based machines operate on steep terrain. Cable assisted machines can traverse steeper slopes by overcoming traction limitations, and increase the stability of the machine.

Early development programs of cable assisted machinery for slopes can be traced back to the military, with extensive testing of systems in the 1950s. Steep terrain cable assisted machinery for forestry has been commercially available in Europe since the 1990s, with a number of different companies offering cable winch products that are either machine integrated or bolt-on products. They have mainly been used on forwarders, although the extension to harvesters has also been successfully commercialised.

In New Zealand, two entities have developed cable assisted excavator based felling (and or bunching) machines:

1. Ross Wood System

This is a two-part system with the winch mounted on and powered by a bulldozer that allows it to be used interchangeably by various machines (Figure 1). This provides flexibility; for example the felling machine is tethered, and subsequently a more standard excavator with grapple is used to pre-bunch and or feed the carriage. The bulldozer acts as the mobile anchor and can readily be moved. The winch has four settings that provide a given level of tension to the cable. To help manage the system safely, a digital clinometer is mounted in the cab and a load cell shackle can be attached between the machine and the cable and the tension observed remotely. The preferred felling machine is a purpose built self-levelling steep terrain harvester, currently a John Deere 850.

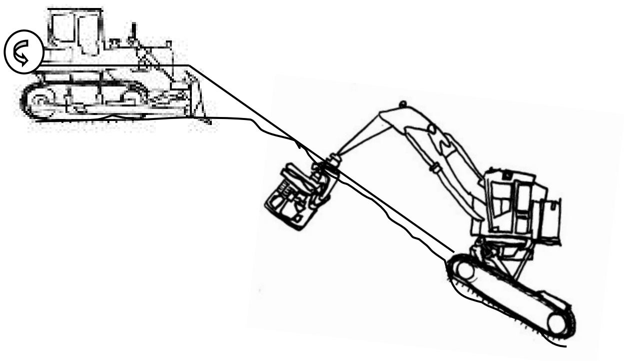

Figure 1: Ross Wood's cable assisted machine configuration with winch on mobile tail hold.

2. Trinder ClimbMAX

This is an extensively modified excavator base with winch fully integrated into the chassis of the machine (Figure 2). The modifications include strengthening

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for forestry work, raising the chassis clearance, modifications of engine and hydraulics to suit steep terrain, lengthening the base for extra stability, and an integrated control system to operate the winch. A blade at the back can be lowered to stabilise the machine on steep slopes if required. With the cable being winched in from the machine, the cable is not being dragged over the ground. It is secured at the top of the slope using a stump, "deadman" anchor or mobile anchor.

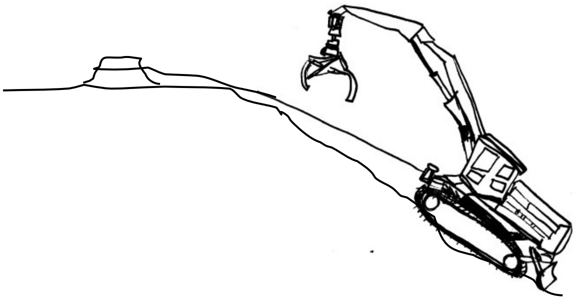

Figure 2: Trinder ClimbMAX cable assisted machine configuration with winch integrated into the machine.

The new Approved Code of Practice for Forestry (MBIE 2012) was released in December 2012. For the first time it contained a specific section for winch-assisted harvesting on steep slopes. Specifically it requires "All mobile plant using the assistance of a wire rope and/or winch shall be specifically designed, tested, demonstrated to be safe", and that "The tension on the wire rope shall be restricted to 33 per cent of its breaking load at all times".

While some studies have been carried out in Europe to test and analyse actual cable tensions associated with operating such machines, no one has tested excavator-based type machines of this size (35+ tonnes), and on such steep terrain (>30 degrees) on felling machines.

STABILITY ON SLOPE

In terms of "failure" of the machine on steep terrain the most serious risk is that of machine turn-over. As shown in Figure 3, if the machine Centre of Gravity (CoG) is on the uphill side of the Pivot Point (PP), then the machine will not roll. Most forestry machines have relatively low CoG and are technically very stable in their intended direction of drive, uphill and downhill.

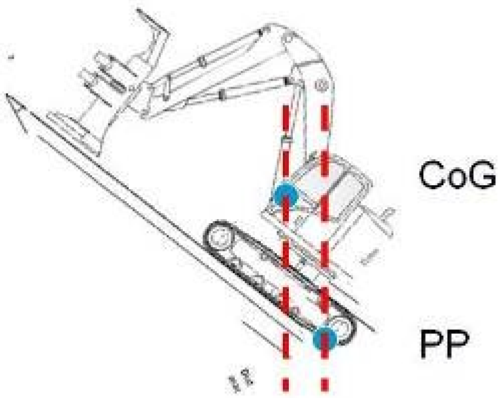

Figure 3: Stability of forestry machines on very steep slopes with centre of gravity (CoG) within track base.

McClean and Visser (2011) showed that the machines with a higher CoG traversing the slope such as a forwarder, or machines that have boom attachments such as felling machines, can easily become statically unstable on very low slopes (Figure 4).

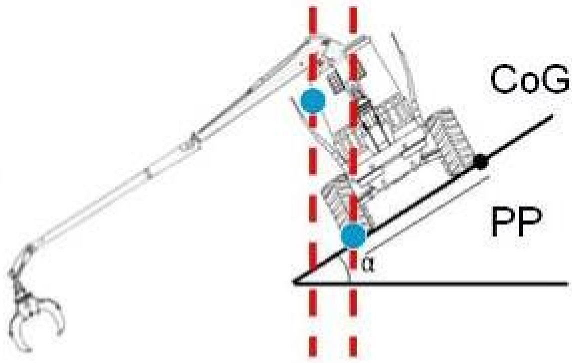

Figure 4: A forwarder with high CoG, traversing across the slope with the boom reaching out to the downhill side will be unstable even on low slopes.

Of lesser concern with regard to failure is the loss of traction which will prevent the machine successfully moving up the slope. However loss of traction that leads to the machine slipping or sliding can have dramatic consequences. It appears that most roll-over accidents on slopes result from a loss of traction resulting in gaining momentum by sliding, and then either hitting a stump or sliding over a bank. As such loss of traction should also be considered a serious failure mechanism.

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Benefits of Cable-Assist

The basic physics with regard to retaining traction on a slope is that the gravity force pulling the machine down (Wg) should not exceed the traction force (T) that the machine is able to develop on the ground. The benefit of the tension provided by the cable (C) will add to the traction force (T), thereby greatly increasing the operating limit of the machine without it reaching its traction limit.

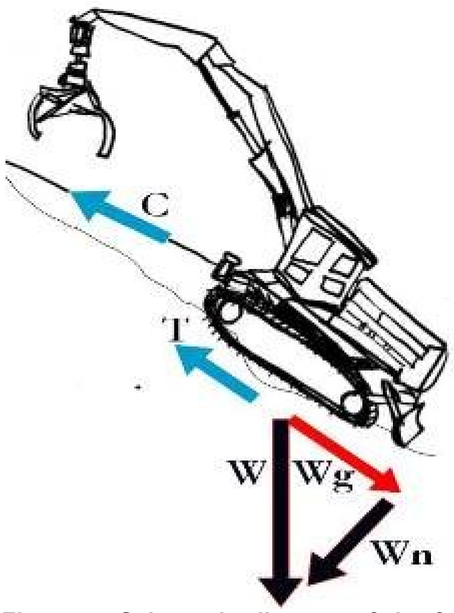

Figure 5: Schematic diagram of the forces of a cable assisted machine on a slope.

In terms of calculations, Wg is simply the product of the downward force (W) by the sine of the angle of the slope. Figure 6 shows the relationship between Wg and the slope angle for a 37-tonne machine.

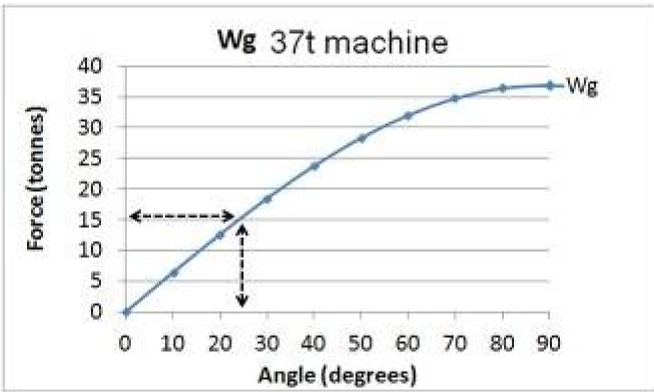

Figure 6: relationship between slope and force Wg.

The traction force (T) is the product of the normal force of the machine on the ground (Wn) with the Coefficient of Traction (CoT). The normal force Wn is defined by the product of the machine weight (W) and the cosine of the slope. As such it will decrease with increasing slope. The CoT is the relationship of the tractive force that can be developed between the tracks and the soil. This is both dependent on the machine (i.e. tracks can typically develop higher traction coefficients than tyres), as well as the inherent strength of the soil (in shear). It is invariably a complex relationship, and further reading is recommended for an improved understanding, but a typical range for CoT is from 0.4 on wet, soft or weak soils to 1.0 for a tracked machine operating on dry firm soil.

Figure 7 shows the effect of slope angle on a range of traction coefficients from 0.4 to 1.0, overlaid on the gravity force. Where the lines intersect represents the limit. For example for a CoT of 0.7 the maximum machine slope is 34 degrees. Also shown on the graphic is the potential benefit of cable-assist. The short black lines represent a cable tension of 10 tonnes. For the previous example of CoT of 0.7, it moves the traction limit from 34 to 48 degrees. Under all scenarios it can be seen that a cable-assist system with 10 tonnes will greatly increase the operating range.

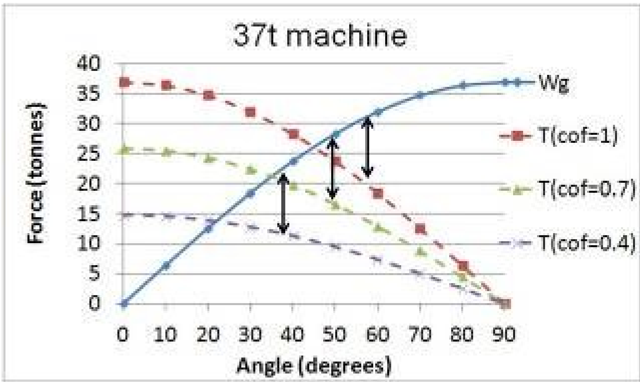

Figure 7: Effect of differing traction coefficients and cable tension on slope limit.

The machines of both systems have cleats on their tracks as can be expected for excavators working on steep slopes. This allows the machine to develop the maximum amount of traction by ensuring any failure is between soil layers, and not between the tracks and the soil.

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DATA COLLECTION METHODS

Data were collect during normal harvesting operation with Ross Woods operating in the Nelson area over three separate days. A clamped tension monitor (Figure 8) was used while operating on a range of conditions up to 38 degrees. With the tethering cable moving, data capture was limited to short segments. Data were captured for moving, felling, shovel and “feeding” the mechanical grapple.

Video footage was captured where possible, and a heart rate monitor was attached to the operator for the duration of the study.

Figure 8: Mounting the tension monitor on the tethering cable.

RESULTS

Example data are presented in Figures 9 and 10. For both figures the time in minutes is along the x axis and the tension in tonnes on the y axis.

In Figure 9 examples of shock loading while operating can be seen between 0 to 0.3 minutes, and then again in the 1.6 to 2 minutes period. Shock loading was quite visible in the movement of the cable while suspended. For times when the cable was primarily on the ground, the duration and scale of cyclic loading was greatly reduced. The period 0.5 to 1.5 minutes is when the machine is in a stationary position and feeding the grapple of the yarder extraction system. The tension of 6 tonnes reflects the setting on the winch.

The three peaks on the right reflect the outcome of the “extreme” test, where the machine locked its tracks and the winch was dialed up to its highest (pull) setting. The peak tensions are very consistent at 20.5 tonnes, which is close to the Safe Working Load (SWL) of 21.6 tonnes for the 28-mm swaged wire rope.

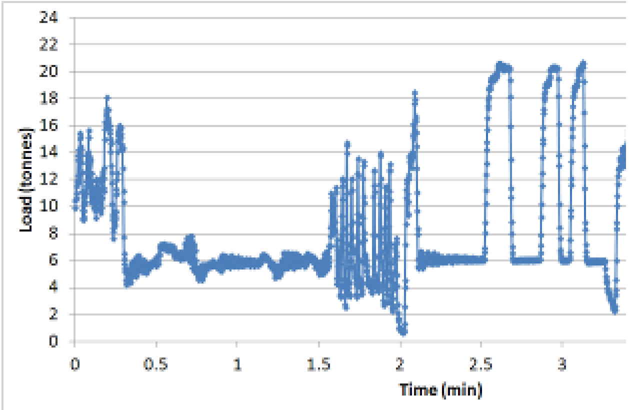

Figure 9: ‘Worst case test’ scenario.

Figure 10 shows the machine moving downhill and felling. The tension setting is at approximately 10 tonnes. The tensions starting at the 4-minute mark, and then again at the 5.3-minute mark are lower because of the binding of the cable on standing trees. Tension is deliberately lowered in the cable when the machine is moving downhill. The cyclic loading starting at 3.7, 5 and again at 6.2 minutes is not shock loading, but simply the cyclic movement of the machine while felling trees.

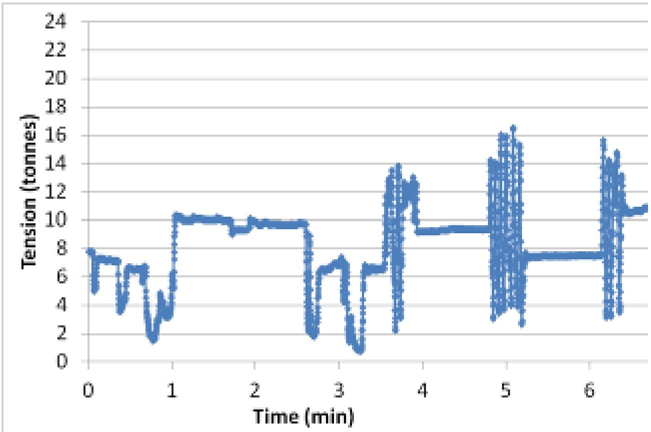

Figure 10: Tension chart showing typical operations with periods of movement (and some shock loading) followed by longer periods of operating (relatively static tension).

When the data were combined there was no evidence of a relationship between the terrain slope and the tension in the cable. The cable tension primarily reflected the winch setting as selected by the operator and the type of operation being carried out by the machine. Greater tension was being used

when climbing with the machine, but equally a very low setting was required to allow the machine to move downhill on the steepest of slopes.

Under normal operating conditions the operator does not engage the higher setting on the winch. The tension in the rope for the tasks of felling, shovelling and feeding the grapple is typically only about 20% to 30% of SWL.

At times it was noted that a tree might be manipulated across the cable, and although clearly visible in the video, little to no obvious increase in tensions was recorded. To avoid wear and tear on the cable near the machine, the first 10 meters has been replaced with heavy duty chain (Figure 11).

Figure 11: Chain used for last section to prevent wear and tear on cable.

With regard to operator heart-rate, Figure 12 shows a sample of the data collected from the operator while operating on some very steep terrain (30+ degrees).

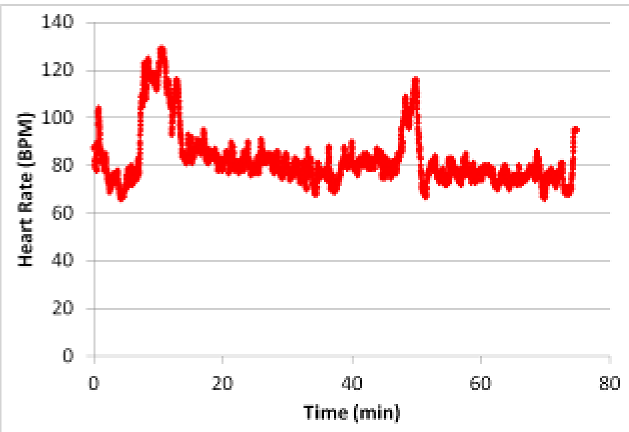

Figure 12: Operator heart-rate for duration of felling on 30+ degree terrain.

It should be noted that the operator was experienced and is recognised for having a very good aptitude for the work. His operating heart-rate of about 80 beats provides no indication of stress. The two elevated periods at 10 minutes and again at 47 minutes are both associated with the operator leaving the cab to carry out maintenance on the felling head.

CONCLUSIONS

This report has shown the fundamentals of why a cable assisted machine is able to more safely traverse steeper terrain.

The outcome of the testing on Wood's system indicates that this bulldozer winch system is able to operate within the safe working limit (SWL) of the 28-mm swaged rope being used. As expected, the largest loads occurred when the highest winch setting was being used with the machine held in place (extreme condition). There was little correlation between slope and cable tension. However, shock loading can occur during a number of operations, including (1) felling large trees where the shock is transferred through to the rope, (2) the rope being snagged around trees or stumps with sudden release, (3) larger vibrations of the rope when it is suspended above the ground and (4) when the rope is being lifted over obstacles using the boom/harvester head.

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