HARVESTING TECHNICAL NOTE

HTN05-06
2013

FALCON FORESTRY CLAW GRAPPLE: PRODUCTIVITY AND ERGONOMICS

Summary

A motorised hydraulic grapple carriage, called the Falcon Forestry Claw has been designed and built by Moutere Logging Limited of Nelson. An elemental time study was carried out on three crews operating the Falcon Forestry Claw at four different sites. The sites all had reasonable deflection, but were on broken terrain with considerable windthrow. Three test variations using the Falcon were compared with manual breaking out using chokers: extracting trees felled motor-manually; using the Falcon to extract bunched trees; and with the Falcon being fed by an excavator on the slope. In average piece size of 1.3 m^3 and average haul distance of 210 metres, manual breaking out using chokers produced 40 m^3 per productive machine hour (PMH). Using the Falcon grapple in manually felled unbunched wood decreased productivity by 9m^3/PMH through consistently lower payloads. However, by either bunching the timber on the cutover, or by feeding the grapple directly, the fast turn-around time of the grapple coupled with large payloads resulted in productivity of 61 and 74m^3/PMH respectively.

Sebastian McFadzean and Rien Visser
University of Canterbury, School of Forestry

INTRODUCTION

In New Zealand cable logging uses rigging configurations that rely heavily on manual breaker-outs ("choker-setters"), requiring them to traverse steep terrain and move heavy rigging equipment. Even with the current implementation of improved safety procedures, breaker out personnel make up a high proportion of total serious harm injuries as well as 14% of all fatalities in forestry, second only to felling (Dept. of Labour 2011).

In an earlier survey of rigging configurations used in New Zealand only 25% of cable operations surveyed had used a mechanical grapple in the last 5 years (Harrill and Visser 2011). Clear advantages of mechanical grapples include being very productive over short distances with good deflection, and requiring no manual breaking out, so they are safer and relatively simple to set up. Disadvantages include increased rope wear, increased number of line shifts due to the inability to lateral yard, and limitations to relatively shorter haul distances (usually due to lower payloads). Concave or difficult terrain limit mechanical grapples as an effective system, and poor operator visibility of stems in the cutover often necessitates the use of a spotter.

Despite these disadvantages examples of innovation to improve existing grapple systems include the implementation of bunching to improve payload, development of camera systems to improve vision and development of a grapple restraint to limit the grapple's ability to rotate feely (Evanson and Brown, 2012). When tested on a swing yarder the grapple restraint showed a significant reduction in average grapple time, at shorter haul distances where a spotter was not required.

Motorising a grapple carriage can achieve a number of advantages, effectively combining positive elements of both the motorised and mechanical grapple carriages. The grapple can be run on an integral tower yarder with two drums (shotgun) or three drums (providing haul back). It is controlled more directly and is able to bring a more direct positive force to hold the payload. Through the use of a rotator the grapple can be turned to facilitate easy pick-up, and the additional control can also be used to increase payload through picking up multiple stems. More robust and lower cost camera technology can be mounted in the carriage to reduce the dependence on clear line of sight for the yarder operator or the use of a spotter (Evanson and Milliken, 2012).

The concept of a motorised grapple is not new. Wood (1970) reported the "Snapper" grapple carriage, a radio-controlled "motorised" grapple carriage using two 12-volt 220 amp-hour batteries operating in the West Coast USA. The batteries powered the grapple for nine hours before needing to be recharged. The carriage weighed 2.5 tonnes, with the grapple opening span reaching 2 metres. In one particular operation the Snapper was recorded to be hauling 5-9 metre log lengths from an average distance of 305 metres, where the average tree diameter was recorded to be 120 centimetres. The crew owner described the Snapper to be performing about five per cent below production figures for a conventional operation, averaging "just less than 200 pieces a day". However, benefits of the carriage included "five men doing the work of eight".

In the 1990s Eagle Skyline Carriages manufactured the Eagle Mega Claw, a remote-controlled, camera assisted grapple with hydraulic actuation of the grapple and 360˚ grapple rotation (Evanson, 2011). It was reported that such innovations may produce faster work cycle times, and consequently increase productivity of cable logging systems.

In 2011 Moutere Logging Ltd in Nelson started the development of a new hydraulic motorised grapple carriage, called the Falcon Forestry Claw. The Falcon grapple uses an internal combustion engine to power a hydraulic motor for grapple opening, closing and rotation. Improvements have included more power, faster grapple movement, and a purpose-built frame that also houses a camera and the radio transmitter. This allows the operator to use an LCD screen with live video feed in the cab to locate stems and control the grapple. The Falcon Forestry Claw (Figure 1) is now commercially available and its use has been reported (Ellegard, 2012).

Figure 1: Forestry Falcon Claw, Prototype 3.

True operational improvements must consider both productive efficiency and operator well-being. Increasing productivity by increasing operator workload cannot be considered an ergonomic improvement. Operating a radio controlled, camera-assisted carriage can affect the yarder operator's workload. The need to operate the yarder itself but also monitor the camera video display, as well as handle the shorter cycle times which remove the short breaks normally associated with choker-setters hooking up the logs, may cause considerable operator stress (Davies, 2012). As such, monitoring and managing operator work load should be an integral part of system improvement.

This report details the first productivity study of the Falcon Forestry Claw. While the Falcon grapple can be used as a substitute for chokers, further mechanisation potential might be realised by partnering with mechanised felling (and/or bunching), or with the use of a steep terrain excavator bunching and feeding the grapple directly. The goal of this study is to provide productivity information relating to stand and terrain factors and system configuration. It is recognised that the Falcon Forestry Claw is relatively new technology and as such incremental improvement both in its mechanical reliability and operator experience, will continue to improve overall efficiency.

METHOD

An elemental time study was used to establish productivity functions for the Falcon Forestry Claw. The study split the yarder work time into elements and the time for each element was recorded using an inbuilt stop watch on a Garmin GPS. Work time elements for each cycle were:

1. **CO** – Carriage out: carriage passes over the edge of the landing until it slowed above the stems to be extracted.
2. **LO** – Load grapple: carriage slows above the stems being hauled until the carriage starts inhaul.
3. **CI** – Carriage in: carriage starts inhaul until it passes the edge of landing.
4. **UN** – Unload grapple: carriage passes edge of landing, logs are lowered and unloaded and the carriage passing edge of landing again on carriage out phase.

A number of other factors were recorded to link stand and terrain parameters:

- **DI** – distance along the corridor, measured using a laser range finder.
- **CH** – Using chokers instead of the grapple.
- **GB** (pre-bunched on hillside), or **EF** (excavator fed)

- **FF** (front face), **AG** (across gully area), or **BF** (back face)
- **BUT** – number of butt logs pulled to the landing
- **TOP** – number of tops pulled to the landing

All delays were timed and categorised:

- **OPD** – Operational delay: Any activity that is necessary for operating the yarder but is not part of the primary function.
- **MED** – Mechanical delay: Any rigging or machine breakdown.
- **DEL** – Any other delay, including social (smoko etc.) delay

At the start of each day a Polar RS800 heart-rate monitor was installed on the yarder operator. Heart-rate data were downloaded and trends over the day checked for trends over longer periods of time. It is assumed that changes in heart-rate over the day related primarily to operator well-being, as very few physical tasks were included in the usual daily routine.

Stepwise linear regression analysis (using IBM SPSS statistics computer program) was used to develop cycle time and productivity equations (covariates or block factors significant at $p<0.05$).

Study Sites and Operations

The study was carried out at four locations using three different crews. All crews were part of Moutere Logging Limited, but experience with running the Falcon varied between crews. Only sites 3 and 4 used the latest version (Prototype 3) of the Falcon. The profile of the terrain at each setting was measured using a clinometer and a range finder, including the slope and distances to the front face and back face, enabling a detailed description of the study areas. Tree size was noted from the harvest plan but checked and adjusted based on sampling actual stems during the study. For the sampling, either stems were measured on the landing (tree diameter at 2 m intervals) to calculate volume, or the output from the Waratah was used. For the purpose of the study, "Butt" logs were assumed to have 85% of the stem volume, and "tops" 15%. Table 1 presents a summary of the sites. Note that on two sites a comparison with chokers was made, and on two sites a steep terrain excavator was available to either bunch or feed the Falcon.

In general the sites had good deflection, but both broken terrain and windthrow (up to 20% of site) made harvesting more difficult.

Table 1: Key Site Characteristics

Site	Yarder	Avg Slope	Avg Tree Size	Avg Haul Dist	Min – Max Dist (m)	Extraction	Bunch/Feed
1	Madill 171	55%	1.3	251m	20 – 430	Chokers	No
2	Berger C19	45%	2.1	321m	100 – 430	Grapple	No
3	Madill 171*	30%	1.6	132m	20 – 190	Chokers	Yes
4	Madill 171*	35%	1.6	211m	30 - 280	Grapple	Yes

*Note: Same crew.

Future Forests Research Ltd, PO Box 1127, Rotorua. Ph: 07 921 1883 Email: info@ffr.co.nz Web: www.ffr.co.nz

Figure 2: Site '3', where the excavator can be seen in the foreground feeding the Falcon grapple.

RESULTS

The data were collected over different extraction distances, and element times for "carriage in" and "carriage out" have been standardised to the standard average extraction distance of 210 meters. Table 2 provides a summary of average cycle elements, and the delay-free cycle time by system type. As expected, the "carriage out" element time (CO) remained relatively constant between the four alternatives.

"Hook-up" or "Load Grapple" element time was clearly reduced with both bunching and feeding. The number of butts extracted while manually breaking out using chokers was double that achieved by the Falcon in unbunched wood (2.9 vs. 1.4) and about 50% higher compared to bunching and feeding the grapple (2.9 vs. 1.9 - 2.0).
"Carriage in" element time was faster using the Falcon, but that was correlated with the reduced payload compared to the other three alternatives. On average, unhooking chokers took 22 seconds longer than unloading with the Falcon grapple.

As the yarder operator was not able to distinguish windthrown trees easily on the camera screen, a higher number of "false" grabs occurred and many of the windthrown stems broke during the extraction phase. With manual breaking out, and when using an excavator to bunch or feed the Falcon grapple, windthrown trees were sorted out and not extracted.

A regression model calculating the total delay free cycle time is shown below in Equation 1.

Equation 1: Cycle Time (min) = 2.36 + 0.007 DI + 0.91 CH +0.41 AG – 0.55 GB – 0.79 EF
Where,

- **DI** = haul distance (m)
- **CH** = using chokers not grapple (=1 if true, 0 if not)
- **AG** = hauling wood from a gulley (=1 if true, 0 if not)
- **GB** = grappling bunched stems (=1 if true, 0 if not)
- **EF** = grappling stems fed by excavator (=1 if true, 0 if not).

Table 2: Summary of total delay free cycle times for respective systems (standardised to 210 m AHD).

	Outhaul (sec)	Hook/Load (sec)	Inhaul (sec)	Unload (sec)	Ave Cycle (min)	Butts (#)	Tops (#)
Chokers	34	119	92	53	4.97	2.9	0.55
Grapple only	31	121	65	32	4.12	1.4	0.32
Grapple Bunched	38	66	79	31	4.04	1.9	0.39
Grapple excavator-fed	36	59	86	30	3.52	2.0	0.30

From the regression equation, every extra 100 metres extraction distance added 0.7 min (42 sec) to the average cycle time. To the standard time with chokers, using the grapple reduced the cycle time by 0.91 min (54 sec). Hauling wood from a gully increased cycle time by 0.41 min (25 sec).

The regression analysis also showed that grappling bunched stems reduced the cycle time by 0.55 min (33 sec), and feeding the grapple from an excavator loader reduced the cycle time by 0.79 min (47 sec). There was no significant difference between extracting from the front or back face that was not already explained by the haul distance factor.

A separate regression model was produced for calculating the productivity of the Falcon grapple in m^3/PMH, as shown in Equation 2.

Equation 2: Productivity (m^3/PMH) = 29.9 – 0.054 DI + 9.4 PS + 9.1 CH – 6.7 AG – 13.2 BF + 30.6 GB + 43.6 EF
Where,

- **DI** = haul distance (m)
- **PS** = piece size (t)
- **AG** = hauling wood from a gully (=1 if true, 0 if not)
- **BF** = hauling wood from back face (=1 if true, 0 if not)
- **CH** = using chokers (=1 if true, 0 if not)
- **GB** = grappling bunched stems (=1 if true, 0 if not)
- **EF** = grappling stems fed by excavator (=1 if true, 0 if not)

As expected, productivity declined with increasing distance (by 5.4 m^3/PMH per 100 m), but increased with average piece size (by 9.4 m^3/PMH per tonne increase in piece size). Extracting stems from a gully decreased productivity by 6.7 m^3/PMH. Hauling wood from the back face decreased productivity by 13.2 m^3/PMH. Although hauling from the front versus the back face was not significant in the cycle time equation, it was significant in productivity analysis. The reason observed was that when pulling across the gully the Falcon grapple at times either lost or broke a stem.

The total productivity of each of the four alternative systems was significantly different. The base case of manual breaking out using chokers achieved 39.9 m^3/PMH. The productivity of the Falcon grapple without bunching was reduced by 9.1 m^3/PMH to 30.8 m^3/PMH despite a 17% reduction in cycle time, the grapple carried half the payload. Grappling pre-bunched stems increased the grapple productivity by 30.6 m^3/PMH to 61.4 m^3/PMH. Using an excavator to feed the Falcon grapple increased the productivity by 43.6 m^3/PMH to 74.4 m^3/PMH.

No cost comparisons were undertaken in this study. Operating with chokers clearly requires additional workers, while using the Falcon grapple involves additional capital cost. Both bunching and feeding the grapple requires an additional feller buncher or excavator loader capable of traversing the steep terrain.

DELAYS

Utilisation rate for the yarders in the study (including Falcon grapple and choker rigging configurations) averaged 56%. As such, delay time accounted for 44% of the scheduled machine hours (SMH) for the duration of the study (13 days). Mechanical delays accounted for 15% of SMH, most of it coming from two incidents. One major mechanical delay related specifically to the Falcon grapple, when it hit the ground causing a hydraulic ram to shear off. The other major mechanical delay was associated with the yarder, when one track came off when it was being turned. Minimal time was spent on regular maintenance of either the grapple motor or the camera.

Operational delays accounted for 15% of SMH, the majority of that time associated with line shifts and rigging adjustments or maintenance. Some operational delays were also recorded when operating the Falcon grapple feeding alternative when the landing could not keep up with productivity, preventing the logs from being landed in the chute.

Other delays totalled 14% of SMH, where the majority of the time was regular smoko breaks and/or interference from the study itself.

While the delays reported are an accurate record of the study, they do not reflect long term average production delays. Without the two major break-downs mechanical delay would be just 2% instead of 15%.Being an innovative, new and exciting system, the trial also resulted in frequent visitor delays. Finally, as with any new system, a learning curve effect will both increase productivity per PMH, and reduce delays per SMH over time.

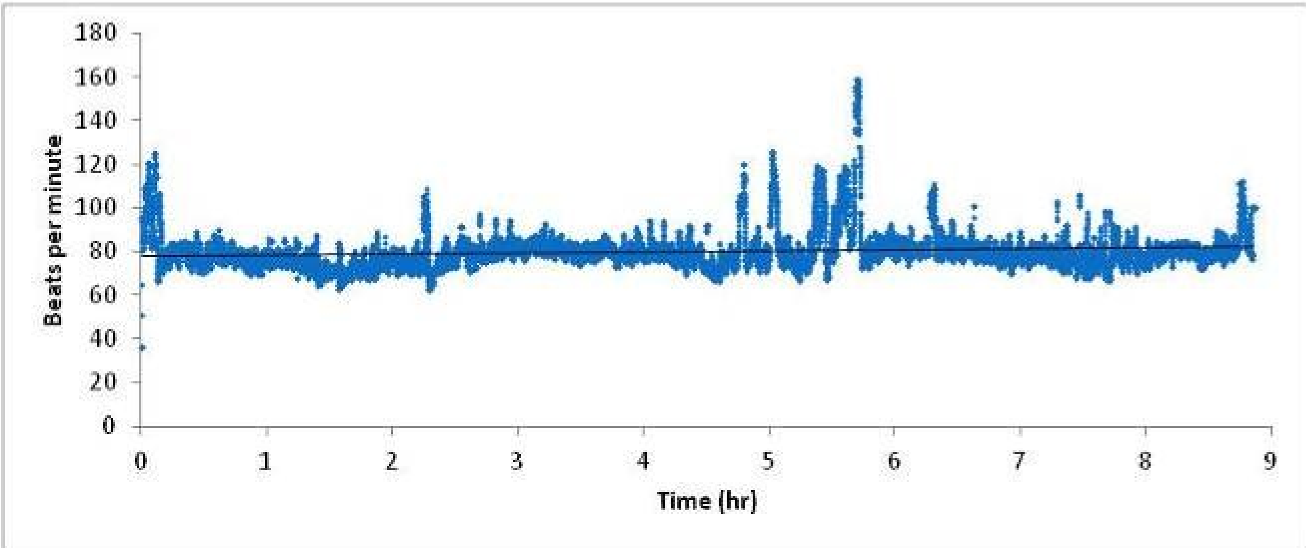

Figure 3: Heart rate data for operator at site three. The spikes in heart-rate all relate to activities outside the yarder cab.

HEART RATE MEASUREMENT

In a short previous short study of a Falcon grapple operation, Davies (2012) reported a significant increase in the heart rate of the operator over the period of half a day. This was consistent with the operator having no breaks and being visibly stressed and at times frustrated in operating the Falcon grapple.

During this study the yarder operator heart rates were recorded to see if operating the Falcon grapple consistently increased operator stress levels.

Figure 3 shows a typical data set for a day's operation (9 SMH). All of the heart rate spikes are associated with the operator carrying out activities outside the yarder cab, such as start-up procedures at the start of the day, moving to and from smoko, or helping with rigging change (at 5.5 hours). This operator's average heart rate remained steady for most of the duration of the day, indicating no fatigue setting in during that time.

Overall, two heart rate data sets indicated a decline in average heart rate, two showed an increase, while the remainder stayed relatively constant. One operator had an average working heart rate of only 80 bpm, while others averaged closer to 100bpm. While a higher average heart-rate can be indicative of higher levels of mental stress, it is more likely to be related to an individual's health. Although this was not a full ergonomic study, it is indicative that overall there was no basis to support the view that operating the Falcon grapple is causing unreasonable work stress for the operators.

CONCLUSIONS

The Falcon Forestry Claw developed by Moutere Logging Limited is a motorised grapple carriage which aims to combine the benefits of mechanical grapples with motorised carriages to increase productivity and flexibility, and remove the safety risk of choker setters working on steep terrain.

This study has provided productivity, delay and ergonomic information from four different sites relating to operating the Falcon Forestry Claw. Overall the Falcon grapple system was effective in operation and the study showed it can be successfully implemented on standard tower yarders eliminating the need for manual breaker outs. In comparison with operating chokers using two breaker outs, productivity was 22% lower in unbunched wood as larger average payloads were accumulated with chokers.

However significant productivity gains were realised using the Falcon grapple when it extracted bunched tree stems in the cutover (+30.6 m3/PMH), or when

using an excavator to directly feed the grapple during extraction (+43.6 m3/PMH). Average yarder operator heart rate data did not indicate undue mental or physical stress during operation of the Falcon Forestry Claw grapple.

REFERENCES

Davies, N., 2012. A case study of operator stress and fatigue from the digital control system on the new Falcon motorized grapple carriage developed by Moutere Logging. Final year Forest Engineering Project. University of Canterbury: Christchurch.

Dept. of Labour, 2011. Forestry Sector Action Plan 2010-13, in Workplace Health and Safety Strategy for New Zealand to 2015. Dept. of Labour: Wellington.

Ellegard, J., 2012. Falcon Flexes its Wings. New Zealand Logger. October 2012, pp25-29. Allied Publications, Auckland.

Evanson, T., 2011. International Grapple / Carriage Developments: A Review of the Literature, Harvesting Report No. FFR-H004, March 2011. Future Forests Research Limited: Rotorua.

Evanson, T. and D. Brown, 2012. Improved Grapple Control using a Grapple Restraint. Harvesting Technical Note HTN04-10, 2012. Future Forests Research Limited: Rotorua.

Evanson, T. and P. Milliken, 2012. Hauler Vision System: Testing of Cutover Camera Harvesting Technical Note HTN05-03, 2012. Future Forests Research Limited: Rotorua.

Harrill, H. and R. Visser, 2011. Rigging Configurations used in New Zealand Cable Logging. Harvesting Technical Note HTN03-11. Future Forests Research Limited: Rotorua.

Harrill, H. and R. Visser, 2012. Matching Rigging Configurations to Harvesting Conditions Harvesting Technical Note HTN04-06. Future Forests Research Limited: Rotorua.

Wood, W., 1970. Radio-Directed Grapple Aids Efficiency for Western USA Logging Operation Battery-powered carriage, opens and rotates grapple in system, in World Wood - An International Journal for Loggers, Foresters, Manufacturers of Wood Products. March 1970, Mounton & Co: Springfield, Oregon, USA.