Automatic control for a self-propelled carriage to enable one-man cable yarding

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Abstract:
We have developed an automatic control scheme for a self-propelled carriage to facilitate cable yarding by a single choker setter. Automating techniques are divided roughly into "automatic traveling" and "automatic unloading" techniques. For achieving automatic carriage motion and for making the carriage stop at a target location, we constructed a prototype odometer system to measure the distance traveled and developed methods to reduce the measured error. A corroborative experiment in which logging was done six times was conducted, and for an average logging distance of 228 m, the maximum deviation from the target location was found to be 0.22 m. In the case of automatic unloading, we measured the hydraulic motor pressure of the hoisting winch drive and designed a technique for detecting when the load suspended from a hoisting cable becomes a "no load." By using this method, automatic unloading from a suspension height of 10 m was done accurately by using an automatic unloading hook when a load was heavier than 100 kg

Keywords: self-propelled carriage, automatic control, one-man cable yarding

1 Introduction

Automation of the cable logging system reduces labor and enhances safety. There are some machines that can control the carriage and make it stop automatically (Heinimann et al. 2001), but no machines have so far been developed for automatic unloading. A small number of trials of automatic unloading systems have been reported in Japan (Yamada 1990). These systems involve automated control of the hoisting winch to stop the loading hook at a preset height. In the present study, we introduce a new method for automatic control of a Japanese self-propelled carriage; the method involves not only automatic carriage motion but also automatic log unloading. It has been clarified that the measurement of the traveling distance for an automatic carriage on the basis of the number of revolutions of the capstan drum or the skyline sheave was inaccurate in previous studies (Uemura et al. 1988 and Ito and Uemura 2003). Therefore, we constructed a prototype odometer to measure the traveling distance. Firstly, the accuracy of measurement of the odometer was determined, and a mechanism to initialize the error was developed. Then, a yarding test with automatic carriage control was conducted to measure the deviation of the stopping spot from the target spot. For automatic unloading, we measured the load that was suspended on a hoisting cable on the basis of the hydraulic motor pressure of the hoisting winch drive and devised a method for detecting the moment when pressure begins to decrease and the moment when there is "no load." When the pressure reaches "no load," the winch is stopped. In this method, when the load is light, there is little change in the hydraulic pressure and detection becomes impossible. Therefore, the boundary between successful and unsuccessful detection was determined. Further, an unloading experiment was conducted to confirm the accuracy of the control.

2 Carriages and testing facility

The carriages used to this study were the Radicarry BCR130H (for automatic carriage motion) and the Radicarry BCR-10B (for automatic unloading) manufactured by Iwafuji Industrial Co. Ltd, Japan (figure 1). These Japanese self-propelled carriages use two cables, a skyline and an operating line, for driving the carriage. Both cables are anchored at both ends. A capstan drum on the carriage winds the operating line to move the carriage in either direction. Table 1 lists the technical data for the carriages. Both carriages were equipped with a programmable logic controller (PLC) for automatic control and for data input/output operations. Tests were mainly conducted at the Forestry and Forest Products Research Institute facility in Ibaraki, Japan. The facility has two towers, of 25 m and 15 m in height, spanning a distance of 125.8 m with a skyline slope that can be changed from 0 to 8.8°. The skyline diameter is 16 mm and the operating line diameter is 12 mm.

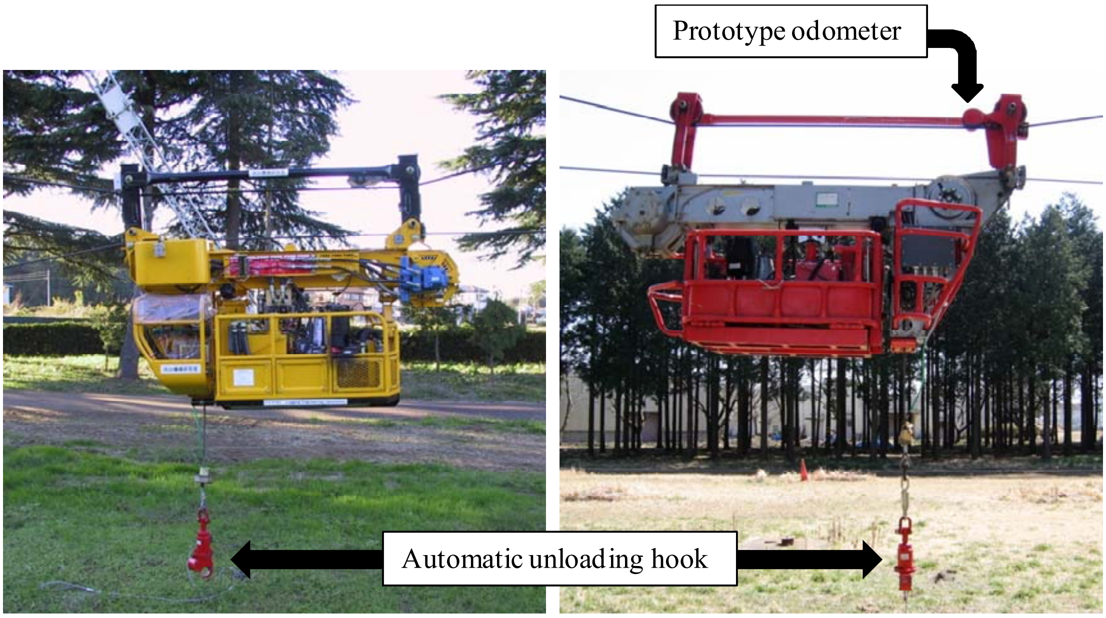

Figure 1: The carriages used in this study: BCR-10B (left) and BCR130H (right)

Table 1: Technical data for carriages

	BCR-10B	BCR130H
Engine power (kW)	7.0	7.3
Carriage weight (kg)	415	535
Pulling power (kN)	9.8	13.2
Carriage speed (m/min)	20–115	20–110

3 Automatic traveling of carriage

3.1 Prototype odometer

The prototype odometer, illustrated in figure 2, is attached to the hanging beam of the carriage. The measuring sheave of the odometer is pressed to the skyline by a stay damper that absorbs the vibration of the skyline. The number of revolutions of the measuring sheave is measured by a rotary encoder connected to the sheave.

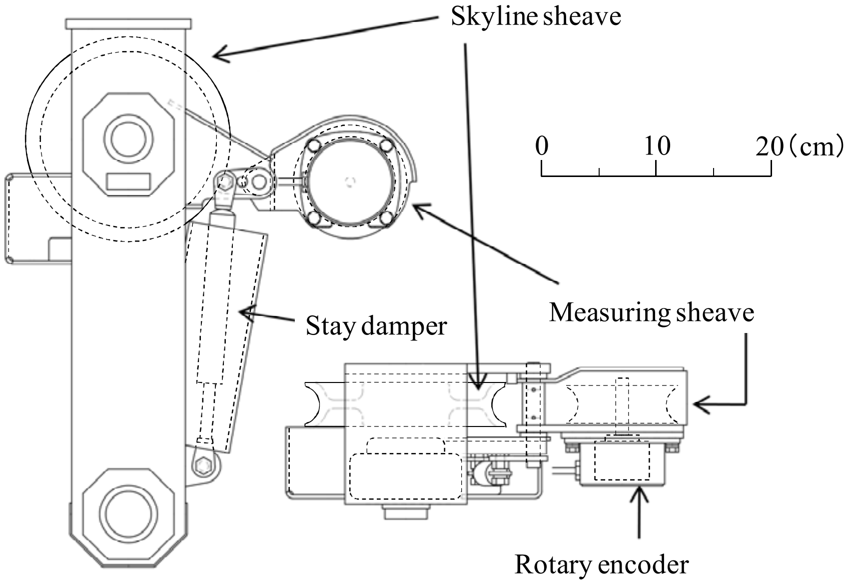

Figure 2: Schematic illustration of prototype odometer setup

The odometer was tested at skyline slopes of 2.3, 4.5, 8.8° with carriage loads (iron weights) of 0, 400, 800 kg to clarify the accuracy of odometer measurement. The carriage carried the weight for a distance of 60 m at total of ten times under each condition. The ratio of error to actual travel distance was then calculated from the values measured by the odometer and the actual travel distance based on surveyed carriage trajectory measurements. The results are shown in figure 3. The error ratio is not well correlated with either skyline slope or load. The maximum error ratio of -5.7% occurred at a slope of 2.3°. The series “Difference” of figure 2 means the difference in average error ratio between 0 kg uphill carriage and each load weight in downhill carriage. It indicates the deviation of stopping spot from target spot per cycle when automatic operation was done in downhill yarding. The difference is no more than 0.5%, showing that the error ratio load weight and direction of carriage have little effect on odometer accuracy. However, because the difference is calculated from average value, it may be increased a little more when it is calculated from actual value.

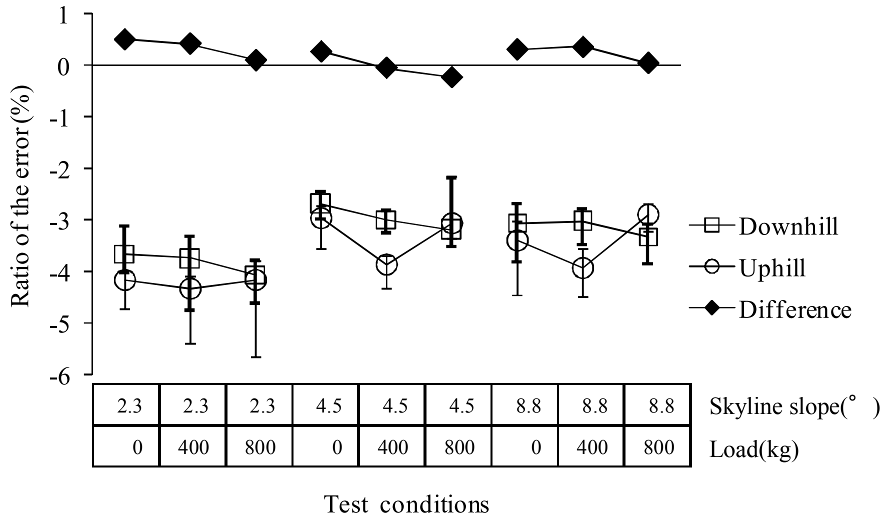

Figure 3: Ratio of measurement error to actual travel distance (negative values indicate underestimation of distance travelled by odometer measurements)

3.2 Initializing measurement error

The measurement error increases in proportion to distance travelled and accumulates with increasing yarding cycles. After many cycles, the stopping location could be expected to deviate significantly from the target during practical use. To maintain accuracy of odometer measurement over time, the accumulated deviation is calculated and corrected for automatically by means of a carriage control point. The control point, shown in figure 4, is installed on the skyline between the landing and the head spar. After unloading, the carriage moves toward the head spar automatically and touches the control point, which triggers a proximity sensor attached to the carriage that calls the PLC to measure the position error. In the next cycle, the PLC predicts the error and corrects the measured distance, applying the error measured during the previous initialization.

Figure 4: Carriage control point for correction of distance travelled

For verification of this correction principle in practical use, trial yarding with automatic control of carriage travel was conducted at an actual working site in a private forest in Chiba Prefecture. The skyline span was 336 m, the average yarding distance was 228 m, and the skyline slope was 2.5°. Each trial involved six cycles, and the deviation in measured horizontal distance travelled was evaluated. The results are shown in figure 5. The deviation in the first cycle was largest, as correction is only applied after the first cycle of use. Thereafter, the maximum measurement error was less than 0.22 m over the 228 m traveled (~0.1%). The stopping point deviated both forward and backward of the target, meaning that the deviation did not accumulate. These results show that the correction functions as expected and provides sufficient measurement accuracy for practical logging operations.

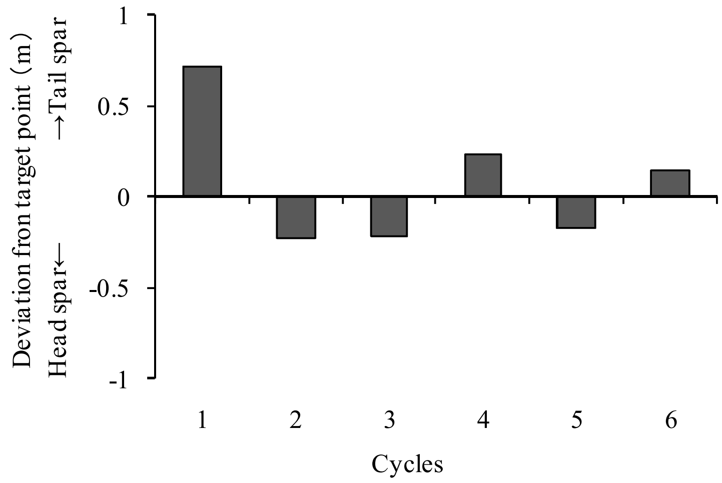

Figure 5: Deviation of stopping point from target point for automated carriage travel with error correction

4 Automatic unloading

4.1 Measurement and control system

A conceptual diagram of the measurement and control system for automatic unloading is shown in figure 6. The oil pressure is measured by pressure sensors installed on both the inlet and outlet ports of the hydraulic motor of the hoisting winch drive. A radial binary encoder pattern is fixed to the side of the hoisting drum and detected by a photoelectric sensor. The PLC counts the detections and calculates the number of revolutions, and then converts these data into the distance by which the loading hook is dropped. An overwinding limit switch is connected to the PLC and functions as a zero point for the dropping operation.

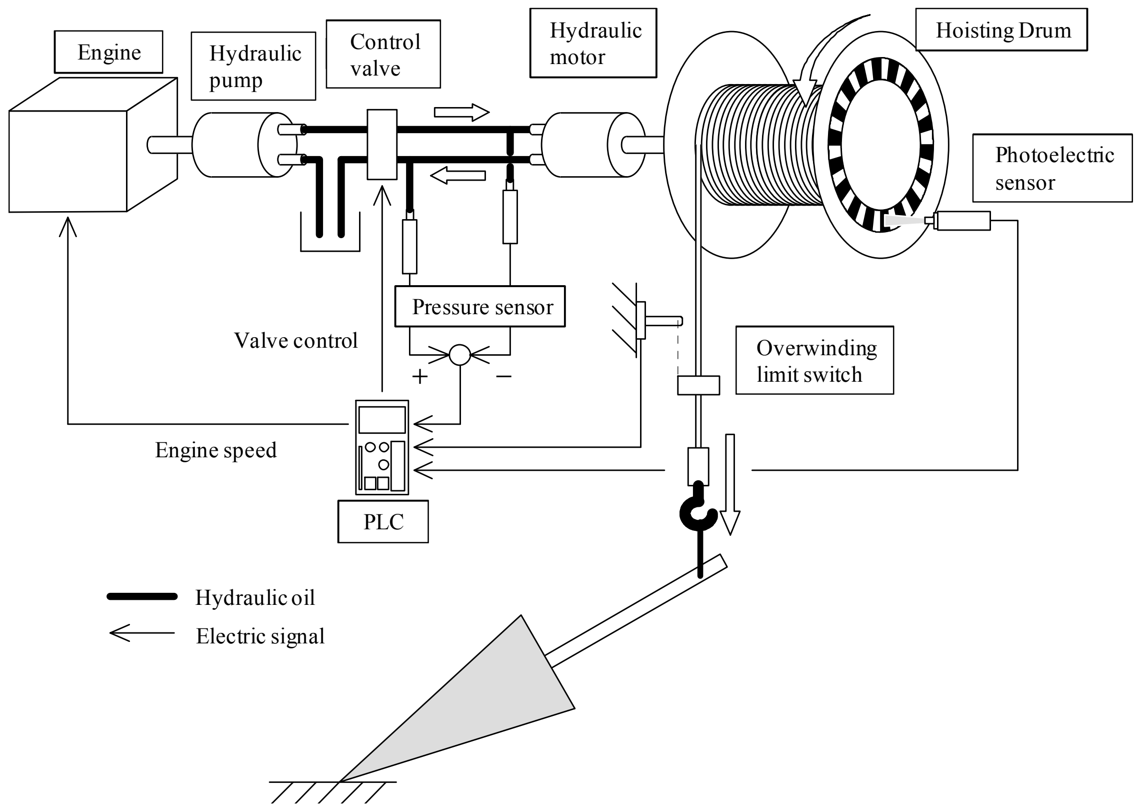

Figure 6: Conceptual diagram of measurement and control system for automatic unloading

4.2 Relationship between load and oil pressure

Figure 7 shows the measured relationship between load weight and average oil pressure as an iron load is dropped using the above control scheme. The lifting height (the carriage height) in this case is about 10 m. The back pressure at the outlet port increases linearly with load weight, whereas the oil pressure at the inlet port remains constant with respect to the load. The differential pressure, corresponding to the load on the hydraulic motor, varies in proportion to the load, and is therefore a suitable parameter for automatic control. As there is little difference in the differential pressure between idle and maximum engine speed, it is assumed that the differential pressure is independent of engine speed.

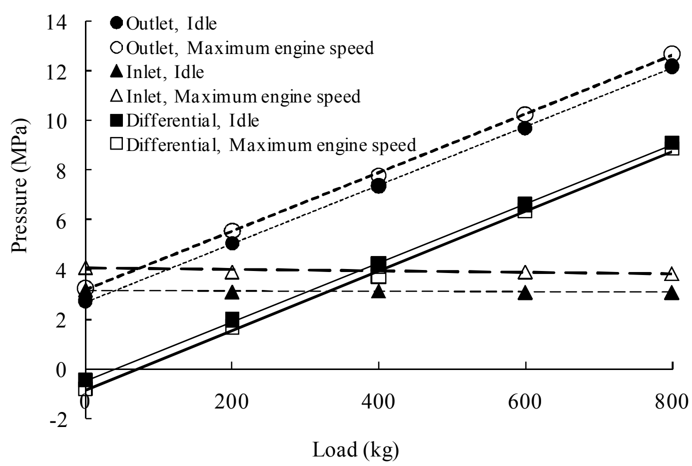

Figure 7: Relationship between load weight and average oil pressure as the load is dropped

Figure 8 shows the change in differential pressure in actual unloading operations for iron weights and two logs (10 m and 4 m long) fastened at various choking points. In the case of the iron weights, the pressure decreases instantaneously after contact with the ground. For the log, the pressure decreases in stages as the log first touches the ground, then declines and is laid down. The characteristic response in log unloading is a temporary decrease in differential pressure soon after contact with the ground due to slackening of the hoisting cable as the cable momentarily drops faster than the log that is being declined. When a long log is choked near its end, there is some possibility of a “no load” condition before the log is fully laid down. When the log is skidded (the log is not hoisted in midair), the pressure change follows the same pattern as for the iron weight.

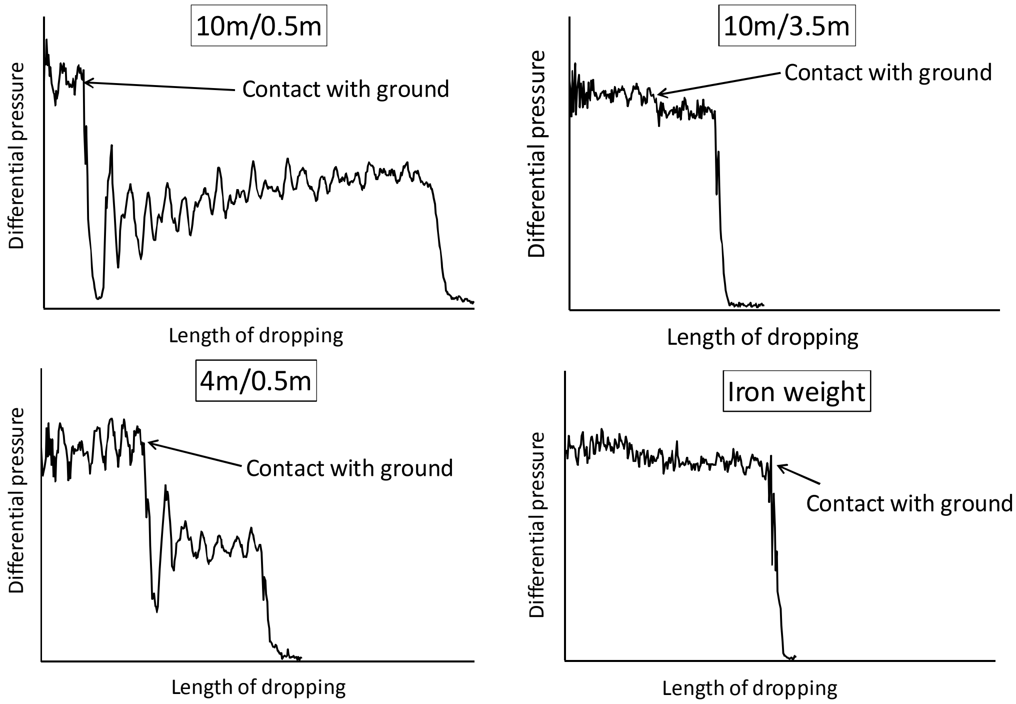

Figure 8: Differential pressure variation (log length/choking point from end of log)

4.3 Methods of parameter detection for unloading operations

A diagram showing the possible methods for detecting the state of a dropping load are shown in figure 9. The moment the log comes into contact with the ground can be detected from a decrease in differential pressure using a dead band (dead band 1) defined by an offset from the moving average of measured differential pressure. The “no load” state when the log is fully laid down is then detected using a second dead band (dead band 2) defined by an offset from the premeasured “no load” pressure. The hoisting winch is stopped when measured differential pressure continues to be lower than upper limit of the dead band 2 while the hoisting drum has made half a rotation to slacken the sling rope moderately. To account for the possibility of an early “no load” signal as observed in actual operations, the true “no load” state is only set when the loading hook is less than 2 m from the ground as determined by the dropping distance and the premeasured carriage height at the dropping point. It is necessary to enlarge the dead band sufficiently to prevent misdetection of the differential pressure signal. Figure 10 shows the relationship between the load weight and the maximum deviation of differential pressure (10 s moving average) under the same experimental conditions as for the measurements in figure 7. The maximum deviation is linearly related to load at both idle and maximum engine speed. The dead band width in this study is therefore set at 1.5 times the corresponding maximum deviation.

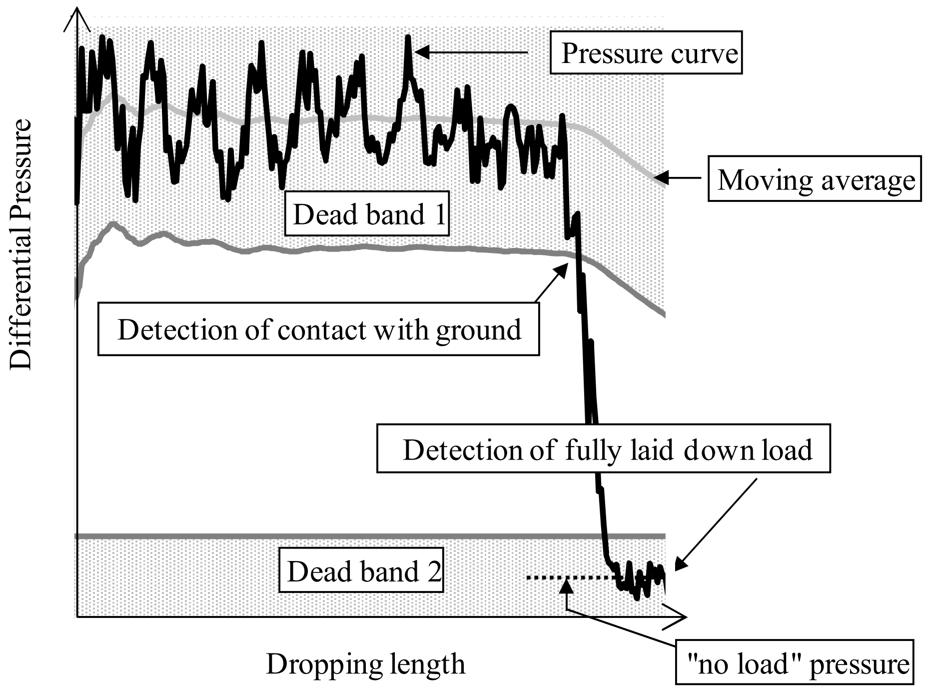

Figure 9: Detection of dropping state from differential oil pressure

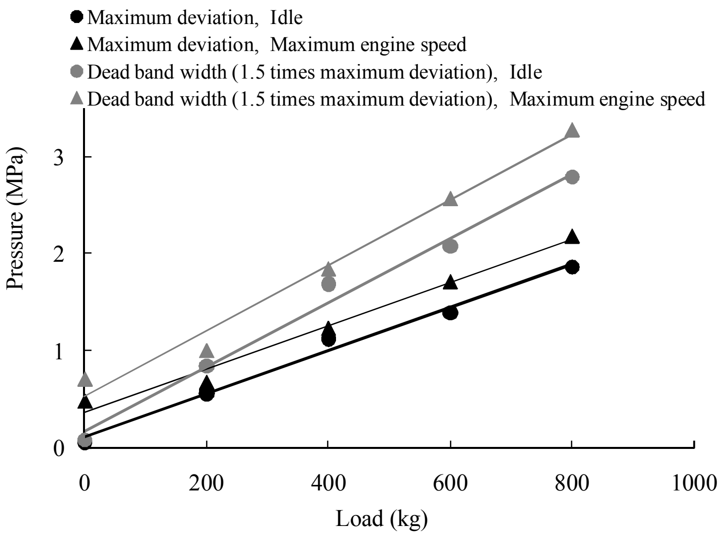

Figure 10: Relationship between load weight and maximum deviation of differential pressure

In this load dropping detection scheme, the drop in pressure for a light load may not be detected because the lower limit of dead band 1 is below the average “no load” pressure. The threshold loads for successful detection calculated from figures 7 and 10 are 18.8 kg at idle and 61.4 kg at maximum engine speed. In the case of lighter loads, detection of the “no load” state is not possible because the measured pressure is lower than the upper limit of dead band 2. In this case, the PLC judges the “no load” condition to occur soon after unloading begins. The calculated threshold load for this detection state is 13.5 kg at idle and 77.7 kg at maximum engine speed.

4.4 Control sequence

The differential oil pressure is measured soon after the unloading sequence begins. When a pressure decrease is detected, the height of the loading hook is calculated. If the height is greater than 2 m, the carriage is controlled such that the log is arranged in the direction of the skyline by alternately dropping the hoisting cable and moving the carriage. If the height is lower than 2 m, the hoisting cable is dropped until the "no load" condition is detected, at which point the hoisting winch is stopped. As the automatic unloading hook used in this study (made by Maruken Industrial Co. Ltd, Japan) releases the load about 10 s after the "no load" state, the PLC is programmed to wait for 15 s after the winch stopped to wait for release before winding the winch up to the zero point. The differential oil pressure is measured during the retraction operation and the winch is stopped if the pressure increases to a level indicating that the hook has not be successfully released.

Before the operation begins, it is necessary to make initial settings at the target location. The values stored in the PLC are the zero point for the loading hook, the height of the carriage at the target location, the "no load" differential oil pressure, and a calibration constant to convert the number of revolutions of the hoisting drum into the dropping length of the loading hook. The zero point is set when the loading hook touches the overwinding limit switch. The "no load" differential oil pressure and the number of revolutions are measured while the loading hook is dropped from a height of 2 m to ground, and the calibration constant is calculated from the total number of revolutions and the height of 2 m. The height of the carriage is defined as the length of the drop for the loading hook when the hook comes into contact with the ground.

4.5 Load coverage

The load coverage of the proposed control scheme was evaluated in automatic unloading tests using iron weights. Ten attempts were conducted at each weight, and the PLC recorded the success of detection. Table 2 lists the results of detection. The threshold for successful detection of initial contact with the ground (initial pressure decrease) is 25–50 kg at idle and 75–100 kg at maximum engine speed. These values are slightly higher than the predicted values. The threshold for detection of a fully laid down load ("no load" state) is 0–25 kg at idle and 75–100 kg at maximum engine speed, comparable to the predicted values. The calculated values are therefore suitable for predicting the load coverage of the automatic unloading scheme. All of the unloading operations proceeded correctly when the "no load" state was detected successfully: the sling rope was slackened moderately, and the automatic unloading hook released properly. In general, the load coverage by this automation method is more than 50 kg at idle and more than 100 kg at maximum engine speed.

Table 2: Results of load tests for automatic unloading operation

Load	Idle		Maximum engine speed	
(kg)	Contact	No load	Contact	No load
0	0	0	0	0
25	0	10	0	0
50	10	10	0	0
75	10	10	0	0
100	10	10	10	10
125	10	10	10	10
150	10	10	10	10
175	10	10	10	10
200	10	10	10	10
400	10	10	10	10
600	10	10	10	10
800	10	10	10	10

4.6 Practical operation

The proposed automatic travel and unloading scheme was evaluated in practical use with logs of 10 m and 4 m in length over a range of choking points (0.5, 1.5, 2.5 m for 10 m log, 0.5 m for 4 m log) and carriage heights (9 and 17 m). Under each condition, ten trials were made with and without automated control for log unloading and arrangement. The final positions of the logs for each test are shown in figure 11. All of the automatic unloading operations proceeded correctly, and the system provides good control over the final orientation of the unloaded log. Without control, the carriages are susceptible to rolling, which causes the log to fall at a right-angle to the skyline direction. Although the orientation of 4 m logs is less uniform than for the 10 m log, it is considered that the orientational dispersion will be improved when the travel distance for unloading is extended. The required width of landings calculated from log length and angle are reduced from 19 m to 2–6 m for a 10 m log without and with control, respectively, and from 7 m to 3–4 m for a 4 m log. These results indicate that wide landings are unnecessary when using automatic unloading and demonstrate the practical utility of the method.

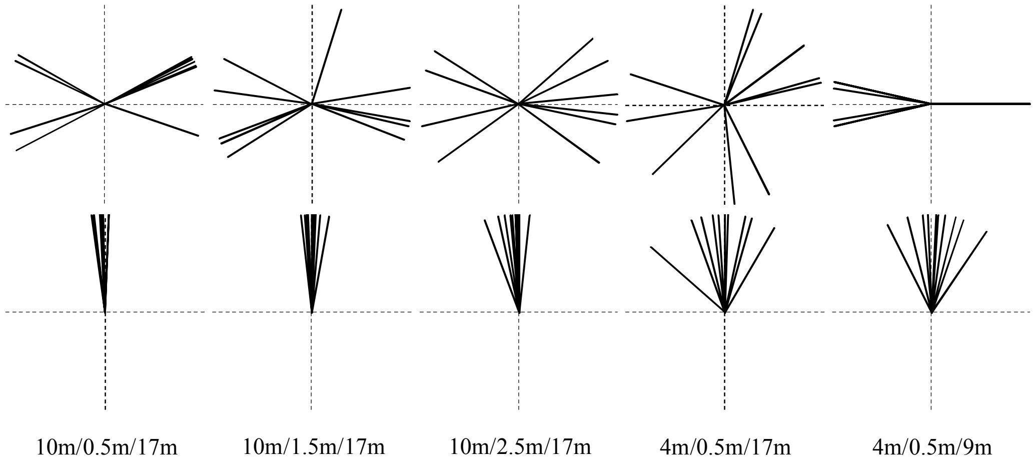

Figure 11: Orientation of unloaded logs (skyline corresponds to vertical axis) without (upper) and with (lower) automatic unloading control (log length/choker position/carriage height)

5 Conclusion

Automatic operations of a Japanese self-propelled carriage –automatic motion and automatic unloading– were achieved, and the operations make it possible for cable yarding to be performed by a single choker setter. The automation method is practical because it is applicable regardless of the log length and irrespective of whether or not the load is hoisted in midair. The devices developed in this study consist of cheap general-purpose components, except for the PLC, and it is expected that for practical applications, they can be built at low cost. Although some errors occurred because of the use of indirect methods (for the purpose of simplifying the device and reducing its cost) to measure the load and the dropping length of the loading hook, the errors were suppressed within the range encountered during practical use by developing methods to correct the errors.

The safety probability and the reduction in labor at the landing improve because the unloading task is performed by a machine, which replaces humans. If the automation technology is improved so that machines such as the grapple loader, processor, and forwarder can work in coordination automatically, additional advantages can be expected owing to a further reduction in labor and improved machine utilization.

6 References

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