REDUCING TRANSPORTATION COSTS WITH CENTRAL TYRE INFLATION SYSTEMS

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Reducing Transportation Costs With Central Tyre Inflation Systems

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Introduction

Forest harvest volumes are predicted to increase from 14.2 million cubic metres from the year ended 31 March 1992 to over 23 million cubic metres by 2005. Previously the forest resource was concentrated predominantly in the Central North Island close to processing facilities or main roads, where a network of well-constructed roads were required to provide the processing facilities with a constant and regular wood supply. Much of the expansion in the resource is in new forests and woodlots being more isolated and remote, increasing the transport distances required in forestry roading, local county roads, and state highways. Various controlled and operational tests on low volume forest roads have proved that management of truck tyre pressures through central tyre inflation (CTI) systems can reduce traffic induced road damage. The reductions found to occur on roads when controlled tyre inflation pressures have been used are in wash boarding, rutting, pot holing, and surface material erosion.

The challenge facing the forestry roading engineer and forestry companies today, is to minimise their harvesting costs by constructing a suitable road to extract all of the available timber with a minimum investment in roading, or the additional expense of two staging the harvesting operations. If a roading engineer knows the vehicles using the road can climb steeper gradients while exerting less pressure on the road than conventional vehicles, then large savings can be realised both in the construction and maintenance of such roading. Extensive testing has shown that CTI allows the forestry companies to reduce their road construction costs by approximately 25% and road maintenance costs by approximately 85%.

The benefits of CTI do not stop with the forestry companies, as the truck operator also receives many benefits by operating vehicles with controlled inflation pressures. These include: decreased tyre wear and tyre damage, decreased dynamic loadings on the chassis and cab reducing vehicle damage, extended hauling season, improved driver comfort, improved traction, and decreased shock loadings on the drive train.

While it is likely these benefits are of interest to the logging industry, the same benefits can also be realised by any transport operation where the vehicle at some stage is operating in an unladen state, at slow speeds, or where traction is of prime importance.

All these features have been documented in a Forest Engineering Research Institute of Canada (FERIC) technical note TN-197 which follows this introduction.

ROADS & TRANSPORTATION
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TESTING A CENTRAL TIRE INFLATION SYSTEM IN WESTERN CANADIAN LOG-HAULING CONDITIONS

A. H. Bradley, R.P.F.

Abstract

This report describes a field trial of a central tire inflation (CTI) system installed on the drive tires of a log truck operating in the Interior of British Columbia. The trial was conducted in 1990 and 1991 by the Forest Engineering Research Institute of Canada (FERIC) and other cooperators. The objectives were to demonstrate CTI technology to the Canadian forestry community, test the performance and reliability of a CTI system under Western Canadian log-hauling conditions, measure tractive improvements offered by a CTI system, and quantify any changes in drive tire and mechanical maintenance associated with using CTI.

Introduction

Pneumatic tires, such as those on a log-hauling truck, are designed to support load while rotating. Tire inflation pressures are generally specified to permit a vehicle to carry a full payload at highway speeds without overheating its tires. Consequently, when the vehicle is partially loaded, unloaded, or travelling at reduced speeds, its tires are over-inflated for the operating conditions. Over-inflated tires can contribute to a variety of problems including increased vehicle vibration, tire wear, occurrence of tire punctures, and damage to the road surface. A central tire inflation (CTI) system permits a vehicle operator to optimize tire performance by varying inflation pressures in response to changing operating conditions.

CTI technology was developed in the 1940's to improve the mobility of United States Army tactical wheeled vehicles. The United States Forest Service recognized, relatively recently, the potential of using CTI systems for reducing construction and maintenance costs associated with low-volume forest roads, and began to seek ways to adapt these systems to heavy forestry trucks. In 1984, the United States Forest Service's San Dimas Technology & Development Center (SDTDC) conducted a trial in which the tires on a log truck were inflated at a level lower than normal with the purpose of investigating what effect this had on vehicle operations and damage to the surface of forest roads. The trial results indicated that lower tire pressures improved vehicle ride, increased drive tire traction, eliminated washboard on the road surface, and healed existing surface ruts (i.e. had the same effect as a rubber-tired compactor) (Della-Moretta 1984). A structured test at the Nevada Automotive Test Center (NATC) found that lowering tire pressures reduced traffic-related road maintenance by up to 80% and healed existing ruts on unpaved roads. This test also found that lowered tire pressures reduced damage to truck components by as much as 87% in trials on rough roads. Reductions in tire wear and punctures were also noted (NATC 1987).

The Forest Engineering Research Institute of Canada (FERIC) initiated a trial of CTI in 1990 in response to a recommendation from an earlier FERIC report entitled *An Evaluation of the Tractive Abilities and Requirements of Highway and Off-Highway Logging Trucks* (Wild 1990). The report concluded that "improvements to the tractive ability of conventional tandem drive-axle tractors are required if larger trailer configurations are to have the same mobility as the traditional pole trailer configuration . . . Two promising methods of achieving such improvements are CTI and [au-

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Keywords: Road transportation, Logging trucks, Tires, Central tire inflation system, Performance, Evaluation.

Author: Allan Bradley is a Researcher in the Transportation and Maintenance Group at FERIC's Western Division.

tomatic slip regulation] ASR systems" (p. 8).

The objectives of this project were to demonstrate CTI technology to the Canadian forestry community, test the performance and reliability of a CTI system under Western Canadian log-hauling conditions, measure the tractive improvements offered by a CTI system, and quantify any changes in drive tire and mechanical maintenance associated with using CTI.

The trial lasted for one year commencing October 1990 and took place in the Interior of British Columbia, near Lumby. Log-hauling conditions in the nearby Kootenay Mountains are some of the most difficult in Western Canada featuring large trailer configurations and steep, winding, rocky roads subject to frequent freeze-thaw conditions. FERIC was assisted in this trial by a number of cooperators. The British Columbia Ministry of Forests (BCMOF) purchased the CTI hardware; R.J. Schunter Contracting Ltd. provided the test vehicle, driver, and shop facilities and materials; Toyo Tire Canada Inc. supplied eight drive tires and technical support; Eltek Inc. reduced the CTI system purchase price and provided product support; and Tolko Industries Ltd. provided planning assistance and the facilities for the field demonstration.

Methodology

The CTI system, which was assembled and installed by FERIC, comprised an Eltek CTI control system and various other auxiliary hardware required to transfer air from the control system to the tractor tires. The Eltek control system was selected for this trial because of the company's experience with the United States forest industry. Four specific hauling phases were identified: on-highway loaded; on-highway unloaded; off-highway loaded; and off-highway unloaded. The application specialists at Toyo Tire Canada Inc. proposed the tire inflation pressures for each of the four phases of the hauling cycle based on tire deflection and the load and speed criteria established by the Tire and Rim Association (1989) (Table 1) (Figure 1). Eltek programmed the controller with the inflation pressures and associated maximum speeds. The Eltek system controlled the inflation settings of only the drive tires on the tractor. The tractive improvements arising from applying CTI control to the other truck tires were considered too little to justify the additional cost and complexity of extending the CTI system to include them.

The driver of the test truck was provided with a log book in which to note details of repairs and maintenance to the CTI system, and observations about changes to daily truck performance, such as gradeability, ride quality, safety, and mobility. Periodically, a data logger was used to record ambient temperature, activity of the inflation and deflation solenoids, vehicle speed, pressure of the truck's air system, and drive tire pressure.

To quantify the tractive benefits of CTI, a drawbar pull test was conducted by pulling a tractor-pull sled across a level, gravel field. A load cell, located between the CTI-equipped tractor and the sled, measured drawbar force. As the tractor pulled the sled, a moveable weight advanced on the sled, increasing drawbar resistance until the drive tires finally broke traction (Figure 2). This test was repeated several times for each of the four inflation settings of the CTI controller.

A demonstration day for government and forest industry representatives was held in March of 1991, at Tolko's mill in Lavington, British Columbia. Presen-

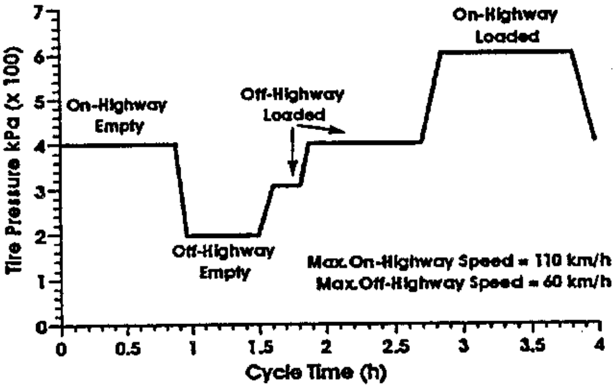


Figure 1. Optimum tire inflation pressures during log-truck duty cycle.

Table 1. Tire Inflation Pressures for Each Hauling Phase of the Trial

Tire pressure (kPa)	Tire pressure (psi)	Tire loading (kg)	Hauling phase	Maximum speed (km/h)
620	90	2200	On-highway, loaded	110
414/310	60/45	2200	Off-highway, loaded	60/30
414	60	1500	On-highway, unloaded	110
207	30	1500	Off-highway, unloaded	60

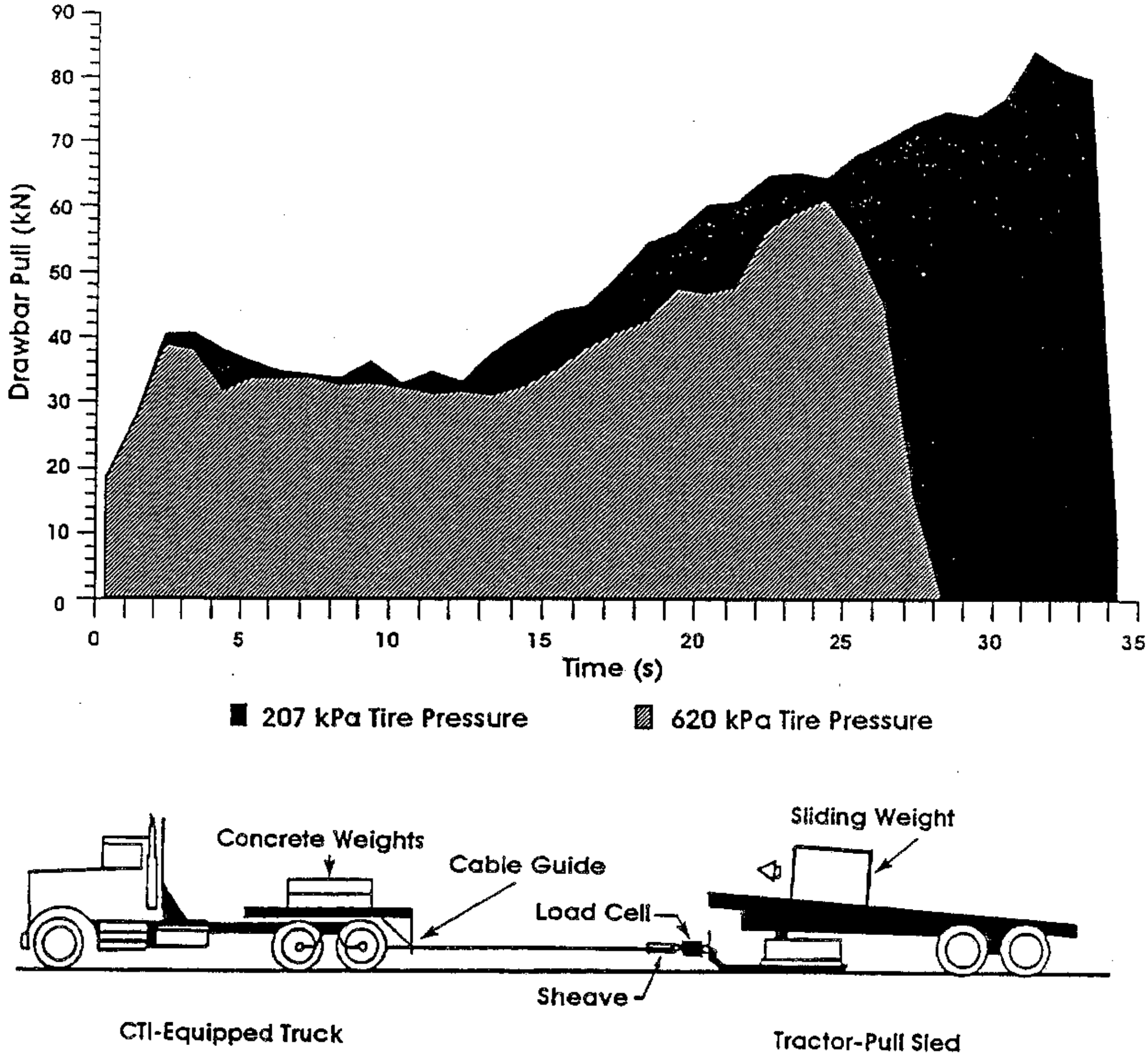


Figure 2. Drawbar pull test arrangement, and sample test output.

tations by FERIC and by Toyo Tire were followed by demonstrations of the test truck's tractive and rough road capabilities.

Eighteen months of complete maintenance and repair records were analysed for the test truck as well as for a control fleet of four other trucks having configurations and haul routes similar to the test truck.

Tire maintenance histories for the test truck and the control fleet were evaluated from data collected over a period of twenty-two months.

The effect of operating tires at variable inflation pressures on carcass structure and tread wear was monitored through periodic inspections by Toyo Tire. Special emphasis was given to identifying potential problems associated with operating tires at low inflation pressures, e.g. belt edge separation, shoulder block stress, chafer separation, liner-to-carcass adhesion, and casing break up at the wrap-up area of the bead. After the tire treads wore out, two tires were dissected by Toyo Tire to further evaluate carcass integrity. Both visual and ultrasonic inspections, with Bandag's NDI Tire Casing Analyzer, were used to determine the re-capability and grade of each test tire not removed for dissection. When these re-capped tire treads wore out, a sample was again dissected to determine carcass integrity. The remaining tires were examined for acceptability for a second re-capping.

Description of Test Vehicle and CTI System Components

The truck used for this trial was a 1988 Kenworth 924 tractor combined with a jeep/pole trailer. Vehicle gross combination weight (GCW) was 48 100 kg.

The CTI system consists of five main components: an Eltek control device that instigates changes in tire pressure and warns the operator about system problems; air priority switches; driver-operated control valves; air lines to and from the control valves; and brackets, rotary unions, and hoses at the drive axle ends (Figure 3). This package of components, intended only for the tractor drive tires, cost approximately C$7300 (1993), excluding installation.

The CTI system operates in a relatively simple manner. When the driver anticipates a change in either load or speed, he selects a different operating mode on the control device located in the tractor cab. In response to this selection, the control device signals either the inflate or deflate control valve to open. Air from the wet tank is directed into the tires when an inflation is initiated, while air is exhausted from the tires through the deflate valve when a deflation is initiated. During either of these procedures, tire pressure is continuously monitored, with the inflation or deflation stopping when the selected mode's target pressure is reached. Vehicle speed is also continuously monitored, and in the event it exceeds that of the selected mode, the control device warns the driver to slow down or select a mode with a higher inflation pressure. Two priority air switches protect the integrity of the air brake system by making air available for tire inflations only when primary air supply pressure, measured at the wet tank, is above 620 kPa (90 psi). A warning light on the control head alerts the driver in the event of a tire puncture or CTI system leak.

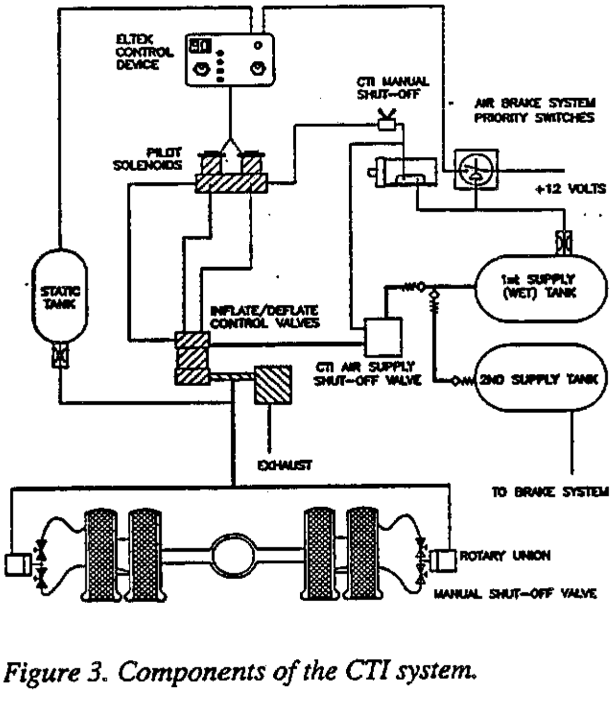


Figure 3. Components of the CTI system.

The tractor's eight 11R24.5 drive tires are linked by a single air line from the control valve assembly. Air is transferred to and from the drive tires through externally mounted air lines connected to rotary unions. This axle end hardware is illustrated in Figure 4. The rotary unions pass air to and from the stationary air lines to the rotating wheels. A bracket mounted on each drive axle hub supports the rotary union and manual shut-off valves; manual shut-off valves, located at the axle ends, permit the isolation of individual tires in the event of a leak. Tire valve cores were removed to permit tire deflations, and to improve air flow.

Installation Process

For the purposes of this trial, Eltek customized the control device with Eprom chips programmed with the speed and tire pressure settings prescribed by Toyo Tire. Eight new M503 drive tires, selected for their good performance in snow and mud and their extended wear on the 70% highway / 30% off-highway trial haul routes, were provided by Toyo Tire.

Installation of the CTI system was a relatively easy procedure requiring common shop tools, approximately 100 hours of labour, and air-brake-rated pneumatic lines and fittings. The axle end brackets were designed by FERIC and manufactured at a machine shop. Eltek provided general system schematics to aid in the installation, but recommended that a brake system expert be consulted as to the proper pneumatic interface for the test vehicle.

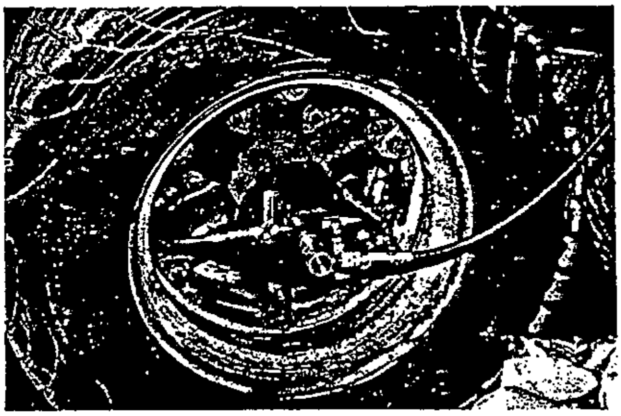


Figure 4. Axle end hardware

The truck's original desiccant-type air dryer was replaced with a Stark, coalescent-type, air dryer. This was done because desiccant-type air dryers are not able to maintain their drying efficiency for the duration of a typical tire inflation. A heated, automatic, tank drain valve was added to the wet tank to improve drying efficiency.

Study Results

Performance Monitoring

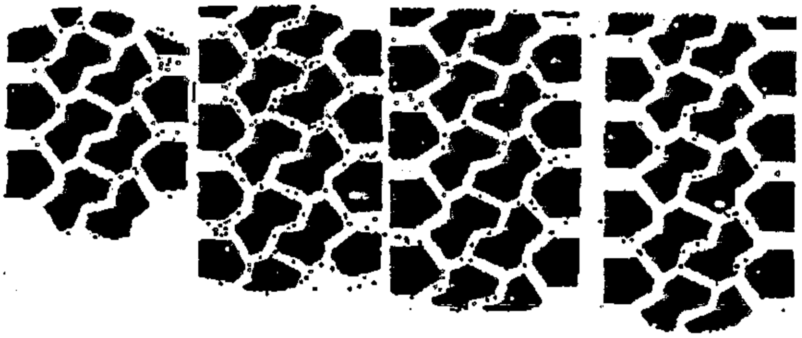
Table 2 presents inflation and deflation times for the CTI system measured under normal operating conditions. The ability of the truck's 7.6 L/s (16 ft³/min) air compressor to supply air for tire inflations did not impede normal hauling operations. Inflation times were found to be influenced strongly by engine speed, e.g. the time required to inflate the eight tires from 207 to 414 kPa increased 46% when engine speed was reduced to an idle. Heavy brake use, which activates the CTI system priority air switches, extended both inflation and deflation times. FERIC's analyses of the data collected with the data logger indicated that ambient temperatures to -10°C did not significantly influence normal operation of the CTI system. However, in subsequent operations, at -20°C and colder, a variety of air system malfunctions occurred related to frozen valves. These problems resulted from excessive moisture passing the air dryer, and were eliminated by regularly draining the air brake tanks and by installing a Stark pre-cooling coil upstream of the dryer.

Figure 5 illustrates the change in the length of the radial tire footprint and tire deflection measured on the loaded test truck as inflation pressure changed. Tire deflection is defined as the difference between the free-standing and loaded section heights expressed as a per-

Table 2. Approximate Tire Inflation and Deflation Times, Measured Under Normal Operating Conditions

	Starting tire pressures			
Final tire pressures	207 kPa (min)	310 kPa (min)	414 kPa (min)	620 kPa (min)
207 kPa	-[a]	1.0	2.2	-[a]
310 kPa	4.2[b]	-[a]	1.0	-[a]
414 kPa	6.3[b]	4.5[b]	-[a]	2.1
620 kPa	-[a]	-[a]	4.4	-[a]

[a] No measurement taken because it is not a standard operation.
[b] Engine at idle.



Tire Pressure	620 kPa	414 kPa	310 kPa	207 kPa
Print Length	25.8 cm	32.0 cm	33.8 cm	36.3 cm
Deflection	8.5%	15%	23%	30%

Figure 5. Changes in tire footprint and deflection with changes in tire pressure (tire load = 2410 kg). (Based on information provided by Toyo Tire Canada Inc.)

centage of the free-standing section height. The length of tire footprint was found to extend by as much as 40% as tire pressure was reduced, while the width of the tire footprint remained virtually unchanged. Note that bias ply tires are not compatible with CTI systems operated on pavements because, when these tires are deflated, the sidewalls deflect excessively and the tread face may deform.

During the study, the axle end hardware required more repair and maintenance than any other part of the system. The supply hoses and the rotary unions extended 7 cm beyond the edge of the tires, making them vulnerable to impacts. The rotary unions were damaged four times during the study by logs dropped on them during loading; however, the externally mounted supply hoses were never damaged. As the driver gained confidence and expertise with the system, he was able to make his own repairs. Of some 600 trips completed during the year-long trial, only two were lost because of damage to the axle end hardware. The control valves required one cleaning during the trial, while the Eltek control system was problem free.

Maintenance of the axle end hardware included tightening fittings and oiling rotary unions. Life of the rotary union seals appeared to be reduced by particulate in the air system and corrosion from road salt. However, no reliable estimate of seal life is yet available because, to date, too few have failed due to wear. Apart from these repair and maintenance details, the driver noted no significant impositions to normal operating routines caused by CTI.

Traction Evaluation

The driver noted the CTI-equipped truck experienced traction gains in slippery, muddy conditions; thus, handling and cornering were improved, and the need to chain tires was reduced. This improved mobility permitted the vehicle to travel faster when off-highway, unloaded, and in muddy or rough road conditions, and sometimes reduced the off-highway unloaded phase of the haul from 45 to 35 minutes. However, the CTI system did not offer the same improvements on hard-packed, icy roads. The driver was unable to quantify tractive gains in terms of gradeability due to changes in operating conditions from trip to trip. He was also unable to compare his truck's gradeability against that of the fleet trucks because only his tractor had all three traction-enhancing devices: a moveable fifth wheel, a sliding kingpin on the jeep, and an inter-wheel differential lock in the tractor's rear drive axle.

FERIC conducted a traction evaluation using a tractor pull sled to quantify the relationship of traction to tire inflation pressure. The test revealed that drawbar pull increased by as much as 39% as tire pressure was lowered from 620 kPa (90 psi) to 207 kPa (30 psi). Wheel hop at spin-out was also eliminated as tire pressures approached 207 kPa. A summary of peak drawbar pull values by tire pressure is presented in Figure 6.

The measured gains in drawbar pull, i.e. 39%, 18%, and 8% of the high pressure value (620 kPa) at 207 kPa, 310 kPa, and 414 kPa, respectively, correspond to equivalent gains in tractive coefficient, which is defined as drawbar pull divided by GCW. To predict the influence of CTI on the test truck's gradeability on loose gravel, the various tractive coefficients were inserted in a gradeability model developed for the loaded tractor-jeep test truck. This gradeability model resembles that for a pole trailer presented by Sessions et al in 1986. Assuming the same tractive increases measured on loose gravel with reduced inflation can be achieved on other road surfaces, a graph was created of the test truck's theoretical loaded gradeabilities for a variety of forest road conditions (Figure 7).

Tire Performance

The eight drive tires tested with the CTI system wore at a rate of 6258 km/mm of tread (Table 3). This represents a decrease in drive tire wear of 90%, i.e. compared to the average of the control fleet, and a 47.5% reduction in drive tire costs, from $7.50 to $3.94 per 1000 km. The re-capped drive tires wore at a rate of 4127 km/mm, achieving on average a 25% decrease in tread wear, and a 20% reduction in re-capped tire costs, from $3.09 to $ 2.46 per 1000 km. Differences in driving technique, and in the arrangement of traction-enhancement devices are acknowledged to affect the tire wear comparison; however, their effect is expected to be small.

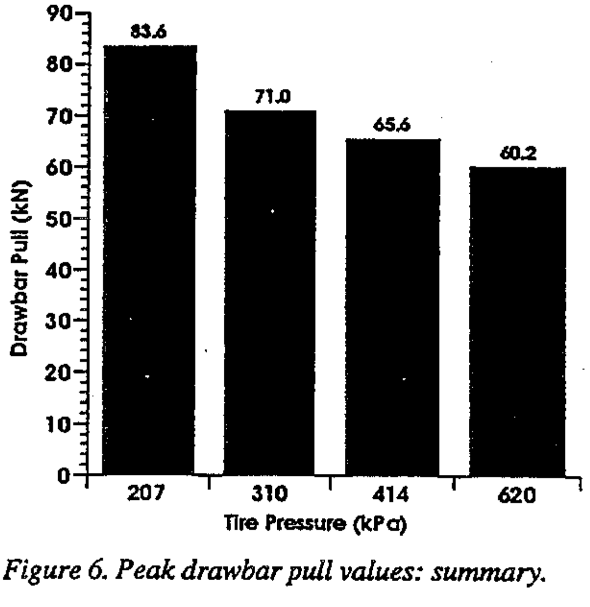


Figure 6. Peak drawbar pull values: summary.

The CTI drive tires experienced no flats during 22 months of operation. Improved drive tire life and reduced drive tire damage resulted in the CTI truck having lower tire maintenance costs than any of the control trucks. Tire maintenance cost, which includes tires, wheels, wheel hardware, and repair labour, was 10% less than the average annual tire maintenance cost of the control fleet. Compared to the average number of tires used by trucks in the control fleet, the CTI truck required 11.3 fewer tires annually. One of the control trucks achieved an exceptional tire-repair record with fewer flat repairs than the CTI truck, the smallest annual tire usage of the control trucks, and an annual tire maintenance cost $180 less than that of the CTI truck.

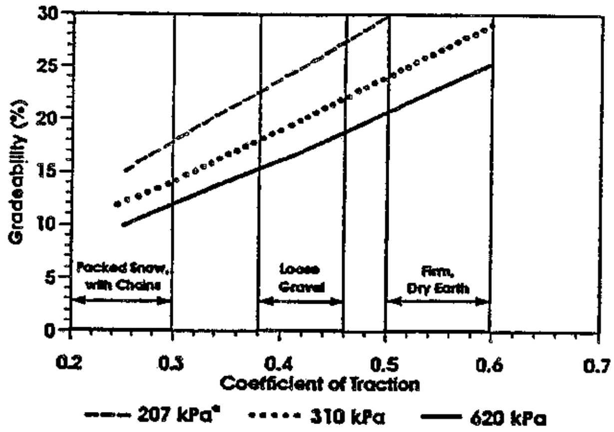


Figure 7. Theoretical loaded gradeability as a function of tire pressure and coefficient of traction. (ᵃ Not used as a loaded test pressure during the trial.)

Six of the original drive tires were inspected prior to being re-capped with Bandag's "Gripper" tread; the remaining two tires were dissected for analysis by Toyo Tire. The tread faces were found to be in exceptionally good condition, having few cuts and almost no chunking of the tread blocks. No sidewall damage was noted. The tires had significantly fewer rock penetrations than is typical of drive tires in logging service in the Lumby area. The CTI tires had 1 to 5 deep cuts to the #3 breaker belt, which compares favourably to the local estimated range of 8-19. Total cuts per CTI tire ranged from 4 to 10 while the local estimated range was 10-25 cuts.[1] The specific results of the inspection of the trial tires prior to first re-capping are given in Table 4. All six tire carcasses were accepted for drive tire service; none were down-graded or rejected. This compares favourably to the control fleet's average rejection rate of 30% for drive tire car-

Table 3. Tire Use and Repairs: Summary [a]

	Control fleet (per truck)	Control fleet (range)	CTI truck	CTI vs control (% difference)
Total tires used (no.)	74.8	(59 - 87)	54.0	-27.8
Total original tires used (no.)	16.3	(12 - 26)	14.0	-14.1
Total re-cap tires used (no.)	58.5	(45 - 75)	40.0	-31.6
Tire usage (no./y)	40.8	(32 - 47)	29.5	-27.7
Tire maintenance cost ($/y)	9 900.59	(8 691 - 11 988)	8 871.72	-10.4
Approximate drive tire maintenance cost ($/y)	4 083.15	(3 740 - 6 828)	3 093.68	-25.2
Average original drive tire life[b] (km)	60 023.0	(51 566 - 68 691)	114 239.8	90.3
Average original drive tire wear rate (km/mm)	3 288.0	(2 825 - 3 763)	6 258.0	90.3
Average original drive tire cost ($/1000 km)	7.50	(6.44 - 8.58)	3.94	-47.5
Average re-cap drive tire life[b] (km)	49 545.0	(35 528 - 56 977)	62 239.3	25.6
Average re-cap drive tire wear rate (km/mm)	3 285.3	(2 356 - 3 778)	4 127.0	25.6
Average re-cap drive tire cost ($/1000 km)	3.09	(2.69 - 4.31)	2.46	-20.4
Flat repairs (no.)	8.8	(5 - 13)	6.0	-31.8
Drive tire flat repairs (no.)	n/a		0.0	n/a
Flat tires replaced (no.)	27.5	(23 - 32)	20.0	-27.3
Tires punctured or damaged (no./y)	19.8	(18 - 21)	14.2	-28.3
Drive tire re-cap rejection rate (%)	30.0	(26 - 38)	0.0	-100.0

[a] Data gathered over a 22-month period, August 1990 - June 1992.
[b] All final tread depths assumed to be 2.38 mm (3/32").

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[1] Doug Mellanchuck, Re-Cap Plant Manager, Kal Tire Ltd., Kamloops, B.C.; personal communication, August 1992.

Table 4. Results of Inspecting Trial Tires Prior to First Re-Cap[a]

	Average (no.)	Range (no.)
Skive outs[a] to #4 breaker belt	4.5	2-7
Skive outs[a] to #3 breaker belt	3.0	1-5
Total skive outs[a] per tire	7.8	4-10
Carcass rejection rate	0.0	

[a] Skive out - At the point of rock penetration, grinding away surrounding rubber and rust to clean the belt surface in preparation for re-capping.

casses. Toyo Tire's analyses of the two dissected tires found no adverse effects of low pressure operation.[2]

After the treads wore out a second time, the six drive tires were again inspected prior to a second re-capping. Kal Tire Ltd.'s inspectors noted that all of the tires were in exceptionally good shape, with five of the six being accepted for drive tire service; one carcass was rejected for re-capping because of an accidental burn on its shoulder that was not related to the CTI system. Bandag's "Waste Hauler" tread was selected for this second re-capping because it offers larger tread blocks than the "Gripper" tread and is expected to provide longer life and adequate winter traction. An analysis of the burned carcass by Toyo Tire has not yet been completed.

Analysis of Truck Maintenance

Reducing inflation pressures of the drive tires improved the ride afforded by the tractor's rubber-block walking-beam suspension. The driver noted that it softened most bumps and eliminated tire chatter caused by small surface rock. The driver had a history of chronic back pain which he found was greatly relieved by the softer ride.

Over an 18-month period, fleet mechanics noted that the CTI truck required fewer repairs than the trucks in the control fleet. The average number of repairs for the CTI truck, at 3.0/month, was 30% fewer than for the control fleet at 4.3/month. The average monthly repair time for the CTI truck, at 9.3 h/month, was 26% less than for the control fleet at 12.6 h/month. The CTI truck experienced 19% fewer vibration-related repairs than the average for the control fleet. These repairs resulted from loosened nuts and bolts; damage to cab components, i.e. gauges and doors; and broken scale pads and lights. Of special note was the 91% less time spent repairing cracks in frames and other components. Average time per weld repair was reduced by 62% from 2.6 h to 1.0 h. A summary of the repair records for the CTI truck and the four trucks in the control fleet is presented in Table 5. Although factors such as equipment age and driving technique will influence the frequency and severity of damage, the differences reported in truck repair are, in FERIC's opinion, largely attributable to the occurrence of less vibration.

Discussion

Performance Monitoring

Both air compressor capacity and air line size influence normal operating inflation times, and should be adjusted to ensure these times do not exceed approximately 10 minutes, otherwise heat-induced tire damage may occur.[3] Because of the added demand put on the air compressor to inflate the tires (approximately 14 min/haul cycle), some increase in repairs to the air system was expected. To date, this increase in repairs has been limited to dealing with the added wear of the air compressor, and has not affected the life of either the air dryer or air governor.

Studies in the United States found that a longer tire footprint provides greater traction and flotation, less wheel slip and slip-related road surface damage, and less damage to the tires related to rock penetration (Della-Moretta 1984, Ad Hoc Central Tire Inflation Applications Team 1988). Toyo Tire estimates that reducing the tire pressures of the loaded CTI truck from 620 to 310 kPa reduces its gross ground contact pressure by 47%, i.e. from 6.5 to 3.4 kg/cm^2. This reduction causes an increase in vehicle flotation and mobility, and may be of great use in forest operations having periodic marginal road conditions. The mobility and road friendliness of an all-axle CTI system are the subjects of a future FERIC study.

Traction Evaluation

The tractive improvements afforded by lower tire pressures may be explained in terms of energy transfer (Simonson 1991):

> Vehicles propel themselves by transferring the energy developed by the engine quite efficiently through the gear train to force on the rotating tire. The transmission of this force is dependant on the driven tire loading and

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[2] Greg Fowler, Technical Department, Toyo Tire Canada Inc., Richmond, B.C.; personal communication, July 1992.

[3] Gary Schultz, Chief Engineer, On/Off Highway Specialty Products, Eaton Corp.; personal communication, August 1992.

Table 5. Average Truck Repairs: Summary

Type of repair	Control fleet Average	 Range	CTI truck	CTI vs control avg. (% difference)
Truck repairs				
Repair time (h/month)	12.6	9.6 - 16.1	9.3	-26
Repairs (no./month)	4.3	3.2 - 5.3	3.0	-30
Welding repair time (h/month)	2.3	0.9 - 4.3	0.2	-91
Welding repairs (no./month)	0.9	0.4 - 1.6	0.2	-78
Average time per welding repair (h/weld)	2.6	2.1 - 2.8	1.0	-62
Vibration-related truck repairs				
Repair time (h/month)	7.7	4.7 - 10.5	6.2	-19
Repairs (no./month)	2.2	1.4 - 3.3	1.6	-27
CTI repairs				
Average CTI axle end repair time (h)			1.4	
Average CTI controller repair time (h)			0.0	
Repairs (no./month)			0.4	

> the coefficient of traction between the tire and road surface (14). However, at the contact of the tire to an unpaved road only a percentage of this energy is transferred to movement, much of it is lost in tire slip and soil shear. This slip excites the road/tire/suspension system and washboarding is a result (7).
>
> On a given road surface with a given tire, CTI introduces the ability to increase the tire/soil contact area reducing the unit shear stress seen by the road surface. When the road surface is able to withstand this reduced shear, less energy is lost to slip and less road damage occurs. At the same time the damping of any cyclic bearing loads is increased by the softening of the sidewall and lengthening of the tire contact patch. These are the main premises behind promoting the use of CTI systems on unpaved forest roads. (pages 11-12)

Lowering tire pressures did not significantly improve vehicle traction on hard-packed, icy roads. In the case of ice, the additions of an interaxle interwheel (four-wheel) differential lock and micro-syped tires are expected to improve vehicle traction.

Tire Performance

Tires on log-hauling vehicles are subjected to very severe duty and commonly fail as a result of rock damage rather than tread wear. Tire costs represent the second highest operating cost, after fuel. A CTI system may offer some relief from high tire costs by extending tread life and reducing rock damage. CTI maximizes tire life by precisely setting and maintaining the tire pressures recommended by the tire manufacturers for all phases of the log haul. Based on the tires' excellent performance and lack of heat-generated damage, the trial pressures appear to have been correctly selected. Operating tires at low inflation pressures reduces wheel slip and creates a more flexible tire carcass. This permits a tire to mould itself over or around sharp roadway rocks, thus resisting being punctured or torn. The results are reductions in tread wear, in cuts in sidewalls and tread faces, and in depth and frequency of stone penetrations.

The difference in the wear rates of the original and the re-capped CTI test tires may be attributed to differences in tread pattern, rubber compound, and/or to the increased percentage of off-highway service seen by the re-caps (41% vs. 30%). The improvement in re-capability may, in part, be a result of re-capping the CTI tires with 7 mm of tread remaining rather than with 3 mm or less remaining which is more usual for tires on local log-hauling vehicles. Because of the traction enhancements possible at reduced tire pressures, some operations may achieve satisfactory performance from tires with less-aggressive tread patterns, thereby realizing longer tire life. A longer-term implication may be the development of tires specifically for use in commercial CTI applications, featuring carcass reconstruction and/or less-aggressive tread patterns.

Maintenance Analysis

By virtue of the reduced wheel slip and softer tire sidewalls created by low pressure operation, a CTI system reduces the amount of chassis and suspension vibration incurred by the truck. A trial that took place on a Nevada testing course found that lowering tire pressures reduced the vibration of some log truck components by as much as ten times and reduced component repair costs by 80% (NATC 1987). Experience suggests that even tractors with air bag suspensions will realize significant ride and traction improvements with CTI.[4] Softer tires, in combination with longer footprints, dampen and reduce drive-train shocks that result when a truck's drive tires slip and "chatter" up a grade (Della-Moretta 1984).

Conclusions

This report documents the results of a FERIC study that was conducted to demonstrate central tire inflation (CTI) technology to the Canadian forest industry; test the performance and reliability of a CTI system under Western Canadian log-hauling conditions; and evaluate the influence of reduced drive tire inflation pressures on truck traction, and tire and vehicle maintenance. The study took place in Lumby, British Columbia starting in October 1990. FERIC was assisted in this study by the British Columbia Ministry of Forests, R.J. Schunter Contracting Ltd., Toyo Tire Canada Inc., Eltek Inc., and Tolko Industries Ltd.

The CTI system was simple to install on the drive tires of the tractor and required little maintenance or repair over the duration of the study, although observations made during the study have led to some recommendations for design improvements.

FERIC, Toyo Tire, and Tolko hosted a field demonstration of the CTI system for FERIC members. In addition to this demonstration, a number of subsequent industry presentations have taken place and have generated considerable interest.

The tractive benefits of reducing inflation of the drive tires were quantified through a tractor pull test, which found tractive gains up to 39% on loose gravel. The maximum grade climbable by the loaded CTI test truck was estimated to increase by 6% and 8% for packed snow and mud over gravel surfaces, respectively. Operationally, traction improvement stemming from lower tire pressures was most notable on the short, steep, muddy grades typical of mountainous British Columbia conditions.

The driver reported reduced vibration and shock loading with reduced inflation of the drive tires. The driver's opinion was substantiated by comparing the maintenance records of the test vehicle to those of a control fleet of similar trucks. Monthly repair time was reduced by 26%, largely because of fewer vibration-caused cracks and loosened bolts, and less cab component damage.

Based on the data FERIC gathered in this trial, if all five of the contractor's trucks were to be outfitted with CTI systems on their drive axles, the projected fleet repair savings would be 16.5 h/month, or roughly 2.0 mandays/month. The CTI system, through reduced wheel slip and increased carcass compliance, was also responsible for reduced tire wear and damage. The rate of tread wear on the original tread surface of the drive tires was 90% lower than wear histories of the vehicles in the control fleet. In addition, the rate of tread wear on the first re-caps of the test tires was 25% lower than for the control vehicles. This improved wear rate made original tire costs 47% less ($3.56/1000 km), and re-cap tire costs 20% less ($0.63/1000 km), than for the control fleet. The test tires experienced no punctures and little rock damage, which led to a comparative reduction in the rejection of drive tire re-caps, i.e. from 30% to 0% over two re-capping cycles. Assuming a mechanic's wage of $45/h, the combination of CTI drive tire savings ($987.50/y) and CTI truck maintenance savings (3.3 h/month) resulted in a benefit to the contractor of $2772/y. Fuel use, vehicle traction, cycle time, and ride quality will influence realized savings also, but these were not studied. The trial inflation pressures produced significant ride, traction, wear, re-capping, and maintenance improvements without the tires incurring any apparent structural or wear defects; therefore, the trial pressures are considered appropriate for the tire model and test conditions.

Recommendations

Log-hauling contractors and forest company trucking managers should consider introducing CTI into their fleets. Improvements to ride, mobility, and tire and mechanical maintenance indicate that log-hauling costs can be reduced. In addition, the recent introduction of CTI-ready axles by manufacturers eliminates the liability concerns associated with retrofitting axles to accept CTI air lines, and should reduce system costs. A long-term cost/benefit evaluation should be undertaken to substantiate this trial's results and to determine the comprehensive effect of implementing CTI systems on a fleet-wide basis. This evaluation should include mechanical maintenance and tire costs, fuel consumption, driver comfort and availability, and truck assists.

Few government regulations currently exist to control the use of CTI systems on heavy trucks. Provincial guidelines based on standards set by the Society of Automotive Engineers (SAE) should be considered to control the safe and consistent application of CTI technology. In the meantime, in the absence of CTI guidelines, installers should consult an air system specialist to ensure compliance with existing vehicle regulations, e.g. Canadian Motor Vehicle Safety Standard

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[4] Blake Hussey, owner/operator of Freedom Logging, Fox Creek, Alberta; personal communication, March 1993.

(1993). The CTI system should safeguard the priority of the brake air supply and should consist only of components rated for use with air brakes.

Evidence from American trials suggests that significant reductions in ballasting or surfacing are possible for aggregate roads carrying trucks employing low tire pressures (Ad Hoc Central Tire Inflation Applications Team 1968). Further Canadian trials should be initiated to determine the influence of CTI technology on forest road surfaces, and to assist the forest industry and the provinces in establishing standards for designing and maintaining forest roads for heavy trucks equipped with CTI control of all tires. In addition, trials should be initiated to determine the optimum tire pressures for minimizing road surface damage. FERIC is in the process of undertaking research in these areas.

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