

Variable tyre pressure control for log-hauling vehicles

E. AMLIN, Group Supervisor, and A. H. BRADLEY, RPF, Researcher, Transportation and Maintenance, Forest Engineering Research Institute of Canada (FERIC), Western Division, Vancouver, British Columbia, Canada

Central tire inflation (CTI) systems allow a truck driver to control tire inflation pressure enroute in response to variations in tire loading and rotational speed. With respect to the Canadian log-transportation sector, the operational challenges of applying CTI technology, the benefits to the truck operator, and the influence of variable tire pressure on vehicle traction on unpaved forest roads were studied by the Forest Engineering Research Institute of Canada (FERIC). For one year, commencing in October 1990, FERIC evaluated the performance of a CTI-equipped 6-axle tandem-drive tractor-jeep/pole trailer combination working in the Interior log-hauling conditions of British Columbia. The results indicate that CTI systems offer significant benefits to the forest industry in terms of traction and tire costs.

1 INTRODUCTION

A variable tire pressure control system, otherwise referred to as central tire inflation (CTI), allows the tire inflation pressures on a heavy vehicle to be changed from the operator's compartment while the vehicle is in motion. Depending on the application, a number of preprogrammed inflations are available that match tire pressures to the load, road type, vehicle speed, and road strength.

This concept is of special interest to the log-transportation sector of the forest industry. Typically, the log-transportation cycle consists of four distinct segments: unloaded/on-highway/high speed, unloaded/off-highway/slow speed, loaded/off-highway/slow speed, and loaded/on-highway/high speed. In Western Canada, the mountainous terrain of British Columbia presents a significant challenge to the gradeability of log trucks, especially on the secondary forest-access roads. Also, demands for increased payloads have caused the industry to move towards using fewer 5-axle combinations and more 6- and 7-axle combinations and this has exacerbated the gradeability problem.

The Forest Engineering Research Institute of Canada (FERIC) introduced the concept of CTI to the Canadian forest industry in October 1990 by undertaking a one-year, one-truck, pilot project in the Interior of British Columbia. A 6-axle tandem-drive tractor-jeep/pole trailer configuration with a gross combination weight of 49 tonnes was selected as the test vehicle. To minimize risk and cost, while not compromising project design, the CTI system was installed only on the driving tires of the vehicle. This paper describes what FERIC has learned about the operational challenges of applying CTI technology, the benefits to the truck operator, and the influence of variable tire pressure on vehicle traction on unpaved forest roads.

2 OBJECTIVES

The objectives of this study were: (a) determine the degree of off-highway traction improvement that may be realized by applying this technology, (b) evaluate, in conjunction with the tire manufacturer, the effects of variable inflation pressures on tire life and tire casing suitability for recapping, (c) compare the productivity and costs of the CTI-equipped truck with those of the control fleet, and (d) demonstrate this technology to the Canadian forest industry.

3 METHODOLOGY

3.1 Setting inflation pressures

Understanding the relationship of tire load, inflation pressure, and speed is fundamental in the application of this technology. Figure 1 illustrates one example of this relationship.

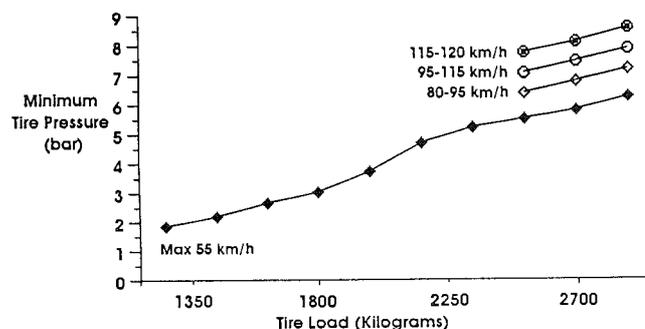


Fig. 1. Load, pressure, and speed relationships: Dual-tire mountings.

(The relationship can vary slightly depending on the specific tire product selected.)

The first step in determining optimal pressure settings was to identify the historical operating speeds and vehicle loading for the various segments of the log-transport cycle specific to the subject vehicle. Typically, log trucks are either fully loaded to maximum legal weight or completely empty. Payload weights, and in turn individual tire loads, are consistent because on-board weigh scales are used. After the load and speed parameters were identified for each of the four operating segments, the tire manufacturer was consulted to establish the respective pressure settings and these were programmed into the controller.

The process of determining proper pressures for each operating segment was crucial to preventing premature tire failure. Under-inflation will cause severe sidewall flexing and excessive heat buildup within the carcass, leading to shortened tire life or disintegration if left unchecked. With this concern in mind, a maximum speed limit for each pressure setting and load condition was also programmed into the controller and an audible alert signalled the driver of excessive speed. The inflation pressures used in this project, the associated speeds, and a typical duty cycle of the test vehicle are shown in Figure 2. In addition to the four usual inflation modes, a low-speed pressure setting of 3.1 bar was provided for negotiating marginal traction conditions when loaded.

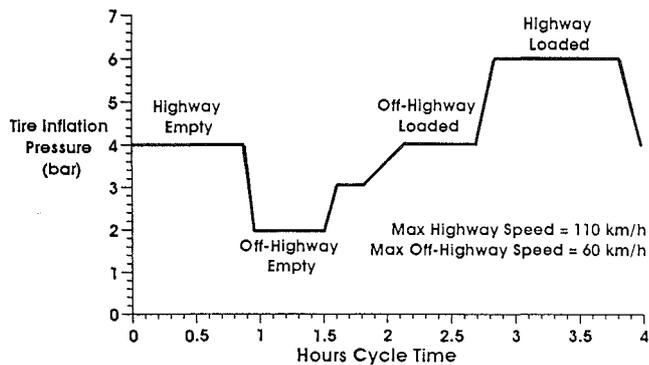


Fig. 2. Duty cycle of the test truck.

3.2 In-service evaluation

The evaluation began in October 1990 with the installation of the CTI hardware onto the truck for controlling only the tires on the two driven axles. The vehicle operator and maintenance personnel received training and information sessions prior to the vehicle resuming operation. The purpose of these sessions was to introduce the technology, explain its operation, and implement the monitoring process as part of the in-service evaluation. To facilitate this, the operator was given a log book in which to record his observations, any incidence of repair, and any related changes in operating procedure or routine. Very important was the need to note any tire or rim damage (including conditions causing such damage), type of damage, tire mileage, tire pressure, and other pertinent facts. The driver was encouraged to note if any changes occurred in daily routine as a result of using CTI, especially regarding gradeability, handling, ride quality, safety, and mobility. Comments were requested to be put in context of load, weather, and road conditions. The operator was encouraged to experiment with the system as varying conditions offered opportunity. Entries detailing repairs, maintenance, or other costs were to be correlated with shop records to determine downtime and costs associated with system use.

Technical representatives from the cooperating tire manufacturer were involved from the onset and, at regular intervals they inspected the tires for defects and wear. Concerns from the manufacturer's perspective included the possible occurrence of belt-edge separation, chafer separation, liner-to carcass adhesion, sidewall damage, and recapping. The tires used in this test were not specially designed, rather they were chosen from existing product lines based on the off/on-highway application of the truck.

3.3 Traction improvement evaluation

With radial tires, tire footprint area increases, primarily through lengthening, and traction ability of the vehicle improves as inflation pressures decrease. To quantify this improvement, FERIC developed a test procedure. The tractor unit was detached from its trailing units and fitted with a ballasting platform over the driving axles. Concrete blocks were loaded onto the platform to provide a vertical weight component of a proportion significant enough to prevent premature loss of traction during testing. Behind the truck was attached a tractor-pull sled which provided a smoothly increasing drawbar demand by means of a sliding weight. The towing linkage consisted of a load cell to measure drawbar pull, a sheave, and a 19-mm swaged steel cable. The cable was anchored at the rear-most end of the walking beams of the truck's drive axle suspension. The cable ran rearwards, horizontally, to eliminate any moments about the drive axles that could influence traction (Figure 3).

A level gravel-surfaced lot of reasonable consistency was selected as the test site, it provided sufficient length to conduct

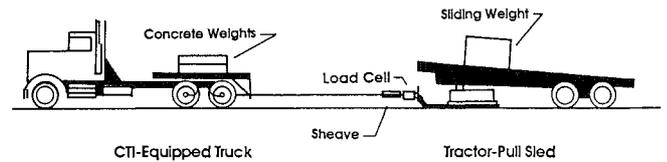


Fig. 3. CTI test truck pulling tractor-pull sled.

unhampered straight-ahead test runs and enough width to provide a new, undisturbed lane surface for each subsequent pass.

The test procedure consisted of the truck pulling the sled forward in a straight line until the truck broke traction. Three or more test pulls were conducted at each of the CTI system's normal operating pressures: 6.2 bar, 4.1 bar, 3.1 bar, and 2.1 bar. The truck, with sled in tow, initiated each test by crossing a starting line at a steady speed of 10 km/h in first gear of the transmission and at full engine rpm of 2100. Movement of the sliding weight was initiated as the rear of the sled crossed the starting line. At the point of complete traction loss or spinout, both the distance pulled and the drawbar force developed were measured.

4 RESULTS

4.1 In-service evaluation

After one full year and 96 000 km of operation, 600 log-hauling cycles had been completed. The loss of two hauling cycles was associated with failures of the CTI system where falling logs at the loading site damaged wheel-end hardware. Similar damage caused six delayed or extended hauling cycles, but did not result in a significant loss of productivity. These latter failures were such that the driver was able to complete repairs on site, by himself, with minimum tool requirements. Through this experience, new installation arrangements of the wheel-end hardware have been developed to offer better protection against this type of damage.

In terms of anecdotal information, the operator reported significant improvements in ride, especially in the off-highway portions of the cycle. Because the truck's speed was lower when travelling off-highway, tire pressures were reduced for both the loaded and unloaded condition and this resulted in an increased spring coefficient of the tire. In turn, the tire was able to absorb more impact energy, thereby reducing vibration of the truck body. During the relatively short term of this project it was not possible to detect a reduction in overall truck maintenance costs that might occur as a result of the softer ride. The operator also noted that there was less need to use tire chains for snow and ice conditions because traction and lateral stability were improved; this was most evident in muddy conditions. The 3-h cycle time was reduced by 10 minutes in these cases.

Manufactured by Toyo Tire Canada Ltd., the model M503 tires were 11R24.5 - 16PR in size. At the start of the study, tread depth on the new tires measured 25 mm. At the end of one year, the tires were removed for recapping with 3-5 mm of tread remaining. None of the eight tires had failed during the test period nor had any abnormal wear or damage been detected. The average life of drive tires for this fleet in similar applications is 50 000 km and this particular set of tires had achieved 96 000 km. Additional benefits, based on Toyo Tire Canada Ltd. reports, indicate a reduction of tread cutting and penetration, less tendency toward compound chip, and no incidence of casing impact failure.

The worn tires were removed from the truck and sent to a recapping plant with ultrasonic inspection and quality control facilities. After the original tread had been buffed away, the

casings were visually inspected for stone penetrations to the structural belt areas. There were 3-to-5 occurrences of stone penetration per casing which is a significantly fewer than the typical count of 20 or more. None of the penetrations caused a casing to be rejected, and the inspection process did not yield any other prohibitive concerns such as impact-related damage. The tires were recapped and returned as drive tires to the CTI application.

4.2 Traction improvement evaluation

The reduction in inflation pressure produced a longer-than-normal footprint and, therefore, greater contact area between the road surface and the tire tread face. Under a constant tire load of 2410 kg, a series of footprint length measurements were established for each of the four pressure settings and these are noted in Figure 4.

During the tests, at the point of breaking traction, a change was noted in the dynamics of the walking-beam suspension. As wheel slip began at the higher pressures, the two drive axles would hop in an oscillating fashion between front and rear causing the truck to shake violently, at which point the driver would immediately stop the test. This type of drive-axle action is typical of log-truck spinouts on unsurfaced roads. At the lowest pressure setting of 2.1 bar, no "hopping" was observed with the onset of wheel spin. Instead, the wheels continued to crawl forward until they had dug 12 to 15 cm into the gravel surface. This change in action at spinout suggests that tires run at lower pressures will climb further, slip less, and create less washboard, especially on grades with firm surfaces.

Drawbar force was measured with a load-cell during each pull. Average peak drawbar pull increases of 5.4 kN (+9%), 10.8 kN (+18%), and 23.4 kN (+39%) were measured at spinout, at which time inflation pressure was reduced, respectively, from 6.2 bar to 4.1 bar, 3.1 bar, and 2.1 bar (Figure 5).

The measured gains in drawbar pull may be expressed in terms of change in tractive coefficient, which is defined as drawbar pull divided by gross combination weight (GCW). In turn, tractive coefficient can be used to predict truck gradeability in truck performance models. Using a gradeability model derived from first principals, the maximum gradeability of the test truck was predicted for a variety of forest road conditions. The traction coefficient was assumed to increase by 18% at 3.1 bar (minimum loaded pressure during test), and by 39% at 2.1 bar (minimum empty pressure during test). Use of 2.1 bar when loaded is limited to traction emergencies at very low speeds, i.e. less than 10 km/h. Table 1 summarizes the results of these gradeability predictions.

5 CONCLUSIONS

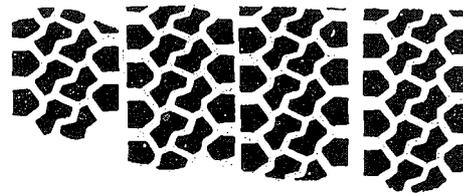
The CTI system used in FERIC's experiment did not prove to be costly to maintain nor did it significantly contribute to vehicle downtime during the one-year evaluation.

The tubeless radial tires used during this test were not adversely affected by the varied pressures delivered by the CTI system. In this case, the CTI concept improved the tire wear rates by a factor of 1.9. Stone penetrations to the structural belts of the tire casings were 75% fewer than the fleet average and impact-related damage was not produced, meaning fewer casing rejections and higher recapping rates than normal.

CTI technology offers significant traction improvements for log-hauling vehicles. Tractive improvements measured in this test ranged from 9% at 4.1 bar, to 39% at 2.1 bar. These traction improvements would be expected to increase truck gradeability as well as improve travel speed and ride.

6 OPPORTUNITIES FOR CONTINUED RESEARCH

Optimizing tire pressures of heavy trucks with respect to load and speed bears further study in terms of truck/road interaction. FERIC will be exploring this potential for forestry roads. However, as this technology continues to develop, CTI systems might also be applied to heavy trucks that use public



Pressure	6.2 bar	4.1 bar	3.1 bar	2.1 bar
Print Length	25.8cm	32.0cm	33.8cm	36.3cm

From Toyo Tire Canada

Fig. 4. Comparison of footprint lengths, for various pressures with a tire load of 2410 kg.

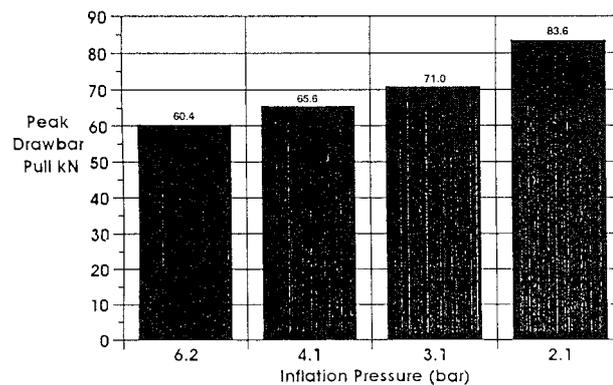


Fig. 5. Average peak drawbar pull, for various test pressures.

Table 1. Predicted gradeability of the CTI-equipped test truck

	Tire pressure				
	2.1 bar		3.1 bar	6.2 bar	
Forest road surface	Loaded (% slope)	Empty (% slope)	Loaded (% slope)	Loaded (% slope)	Empty (% slope)
Snow, 3 cm, on ice	14	26	12	10	18
Snow, 5 cm, packed	18	32	14	12	22
Earth road, firm, damp	21	42	17	14	27
Gravel, muddy surface	24	44	19	16	29
Gravel, hard packed	30 ^a	74 ^b	30 ^a	25	48

^a Power-limited grade.
^b Requires low gear.

highway systems as a factor in controlling infrastructure maintenance costs.

Tire development could also be influenced by CTI technology as less aggressive tread designs for traction would be feasible, and the need for cut- and chip-resistant compounds may be reduced. A modified carcass shape may be more ideal for variable pressures; modifications could include a revised crown radius, modified bead contour, and a straight sidewall design.

Fuel consumption is bound to be influenced by the application of CTI technology, but this remains a factor of some uncertainty.

The need for further product development is evident. For example, rather than using add-on hardware, air delivery systems of increased efficiency could be integrated into such standard truck components as wheel assemblies and axles.