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CENTRAL TYRE INFLATION TRUCK PERFORMANCE TESTING

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Figure 1 - Vehicle configuration for drawbar pull test.

ABSTRACT

To obtain a better understanding of the effects of central tyre inflation (CTI) systems on truck performance under local conditions, a series of tests was conducted on logging trucks operating at various tyre pressures. Tests investigated truck gradeability and fuel consumption. Results show that when operating with low tyre pressures, truck gradeability is improved on most surfaces and fuel consumption increases on hard surfaces. The tyre life and wear did not appear to be adversely affected by short periods of low pressure running. Repairs and maintenance for the CTI system are also presented.

INTRODUCTION

Central Tyre Inflation (CTI) systems allow the pressure in a vehicle's tyres to be adjusted while in motion to suit the specific operating conditions. Lower tyre pressure influences truck/road interaction in the areas of gradeability and road damage.

There are trade-offs in attempting to optimise these tyre pressure effects which must be balanced with factors such as fuel consumption. To fully utilize a CTI system and the benefits it can provide, a good understanding of the system performance under local conditions is necessary. This report presents the results of testing undertaken by LIRO to investigate the use of CTI systems on logging trucks under New Zealand conditions. Testing included truck gradeability and fuel consumption. A truck fitted with a CTI system, as described in a previous LIRA report, was used for the majority of this testing (Jones & Smith, 1991).

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GRADEABILITY TRIALS

Background

Overseas experience indicates that a major benefit of CTI is the improved traction obtainable at lower tyre pressures. To quantify this benefit, LIRO undertook a series of tests to determine the gradeability of the CTI test truck operating at different tyre pressures on different surfaces. Two other logging trucks of different configurations were also tested.

The gradeability of a vehicle is defined as the maximum adverse percent grade it can climb continuously without losing traction. Gradeability is dependent on the road surface as well as the vehicle characteristics.

To determine the gradeability of the trucks, drawbar pull tests were conducted and the results of these used to calculate the gradeability.

A simple methodology was used to calculate the gradeability of the truck as outlined below (Wild, 1990):

$$G_{max} = \frac{DBP_{max}}{GVW} \times 100\%$$

G_{max} = gradeability (maximum % grade)
DBP_{max} = maximum draw bar pull (kg)
GVW = gross vehicle weight (kg)

Site Characteristics

The tests took place at a variety of sites on different surfaces, as outlined below. A level section of road or track, 50-100 metres long, was used for the tests.

Volcanic Soil - The first test took place in the log yard at the Kinleith Mills. The soil was a fine uniform ash with no aggregate present. The surface had been rolled in preparation as a base for a gravel track.

Gravel Road (1) - A section of previously used gravel road was chosen as the test track in Maramarua Forest. The road was wet, well compacted and had a 3% adverse grade.

Sand Track - An access track for trucks on bare sand formed a test site in Woodhill Forest. The sand was wet and the track had been used before by trucks during logging of the area.

Bark/Mill Waste - A short access track covered with sawmill waste provided another surface in Woodhill Forest. The bark, shavings and general wood scraps had been placed over a sand base to a depth of 30-50 cm. This surface was wet and partly decomposed.

Clay Surface - A freshly exposed area of sandy clay in Woodhill Forest was used as a test surface. The soil was damp and sticky but provided reasonable traction.

River Run Gravel Road (2) - A series of tests was conducted in Golden Downs Forest, near Nelson, on a section of road constructed from river run gravel (all passing a 100 mm screen) on a compacted Moutere gravel base. The surface was wet and slightly slushy with a 2% adverse grade.

Equipment

An 8 x 4 self-loading truck with a two axle pole trailer, equipped with a CTI system was used for all of these tests except the river run gravel trials. Two other trucks were tested on the river run gravel; a 6x4 truck with a three axle longs trailer, and an 8x4 truck with a four axle shorts trailer. The trucks were fully loaded with logs for all tests, and the gross vehicle weight (GVW) measured on a weighbridge. The towed vehicle was a large water tanker for the volcanic soil test at Kinleith (Figure 1). Bulldozers were used as the towed vehicle for all the other tests. A load cell connected between the towed vehicle and the rear of the logging truck was used to measure drawbar pull.

Test Procedure

The test truck, in first gear, pulled the towed vehicle forward until a steady speed was reached. The brakes on the towed vehicle were gradually applied until the test truck lost traction and the drive wheels began spinning. Data from the load cell were recorded four times per second on a Husky Hunter portable computer.

On each surface several tests were conducted at a range of tyre pressures. Tyre deflections were measured at each pressure. The truck was driven along different parts of the test track for each test run so that it would not lose traction on previously disturbed areas.

Results are reported in terms of tyre deflection as the tyre footprint size is determined by the deflection rather than the absolute tyre pressure. It should be noted that different brands and sizes of tyres will have different deflection characteristics. The deflections given in the results are averages of the tyres measured at the time of the tests.

Test Results and Discussion

Figure 2 shows the increase in drawbar pull with increasing tyre deflection for the volcanic ash tests at Kinleith. The deflections given are for Bridgestone 11R22.5 L301 tyres. Between 20% and 28% deflection, the increase in drawbar pull is only 210 kg, compared to an 1100 kg increase between 15% and 20% deflection.

These results suggest diminishing gains in drawbar pull for tyre deflections greater than about 20%. United States Department of Agriculture Forest Service (USFS) drawbar pull test results also indicate reducing gains in traction beyond 20% tyre deflection (Ashmore & Gilliand, 1987).

In practice, a lower limit of 20% deflection will result in the best compromise between increased traction and minimum re-inflation time.

A summary of the tests on various surfaces is shown in the Tables 1-3. These results show the maximum gradeability obtained, and the corresponding tyre pressure. The gradeability at the standard highway pressures is also given for comparison. The gradeabilities shown here have been adjusted for any existing grade on the test road.

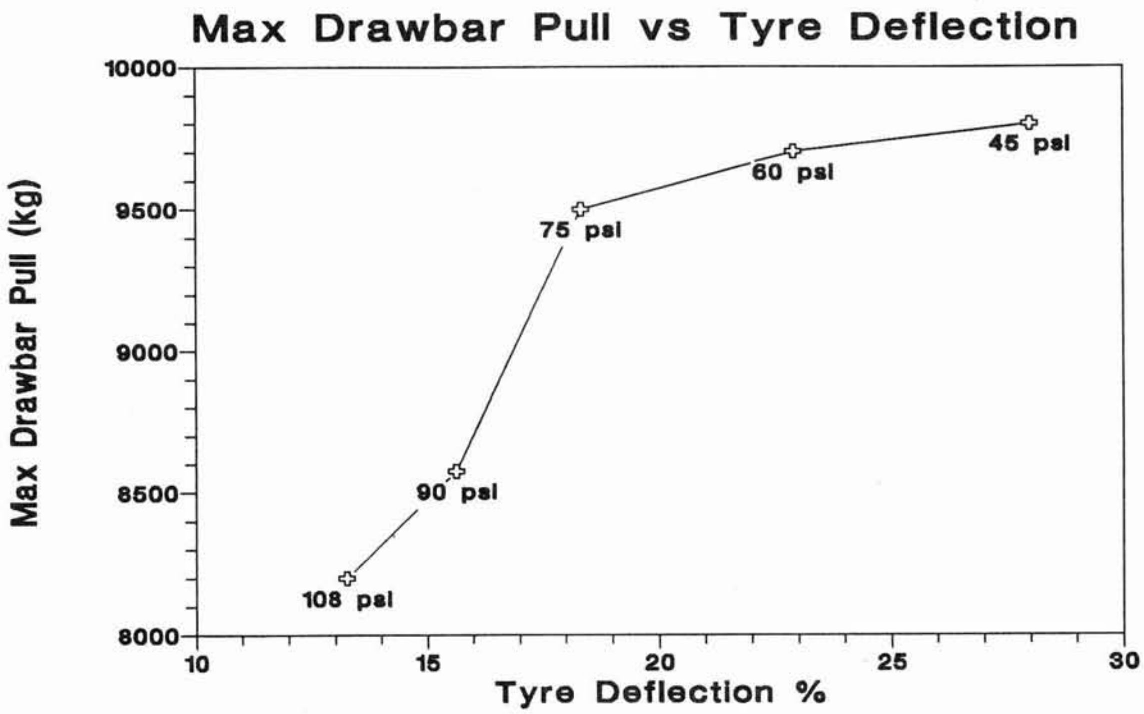

Figure 2 - Maximum drawbar pull versus tyre deflection (CTI 8x4 on volcanic ash soil)

A large increase in traction was obtained on sand when tyre pressures were lowered. Significant increases were also obtained on gravel and bark. Sandy clay, however, behaved quite differently and better gradeability was obtained at high tyre pressures than at low. This effect is due to the properties particular to frictional type soils, and agrees with results presented by Salm (1987).

Note in the above tables that tyre deflection is a function of GVW and even though tyre pressures may be the same, the deflection varies considerably depending on the load carried by the tyres.

The 8x4 truck with a four axle trailer showed an 11% increase in traction, improving gradeability from 17.3% to 19.2% when operating low pressure tyres.

Although the drawbar pull tests with the 6x4 longs truck did not show any conclusive increases in traction at lower tyre pressures, this truck achieved better gradeability, with a maximum of 22.9%, than the 8x4 trucks. This truck had a similar weight on the drive axles to the 8x4 truck tested on the same surface, and thus would be expected to have comparable tractive performance. It is not known what caused the better traction of the 6x4 truck, but it is possible that different suspension configuration and different tyres may have contributed. The lack of a measured increase in traction at the lower tyre pressure for this truck is thought to have been caused by changing road conditions over the course of the trial.

On most surfaces trucks could be expected to climb grades 2-3% steeper by lowering the tyre pressure to give deflections of around 20%. By utilising CTI to increase truck gradeability, an increase in road grades may be possible. An increase in road grades of 2% has the potential to save the New Zealand forest industry millions of dollars each year (Wall, 1987).

Surface	GVW (kg)	Tyre Pressure kPa (psi)	Tyre Deflection (%)	Maximum Drawbar Pull (kg)	Maximum Gradeability (%)	Gradeability at 690 kPa (%)
Volcanic Soil	57,200	310 (45)	28.0	9870	17.1	14.6
Sand	45,180	310 (45)	18.4	7800	17.3	5.5
Bark	45,180	310 (45)	18.4	7200	15.9	12.7
Gravel (1)	42,000	310 (45)	17.0	5300	15.6[1]	12.0[1]
Clay	45,180	690 (100)	13.5	4020	8.9[2]	8.9

Table 1 - Gradeability of the CTI 8x4 truck with two axle pole trailer

Surface	GVW (kg)	Tyre Pressure kPa (psi)	Tyre Deflection (%)	Maximum Drawbar Pull (kg)	Maximum Gradeability (%)	Gradeability at 655 kPa (%)
Gravel (2)	50,560	280 (40)	14.5	8720	19.2[1]	17.3[1]

Table 2 - Gradeability of 8x4 truck with four axle shorts trailer

Surface	GVW (kg)	Tyre Pressure kPa (psi)	Tyre Deflection (%)	Maximum Drawbar Pull (kg)	Maximum Gradeability (%)	Gradeability at 655 kPa (%)
Gravel (2)	45,360	655 (95)	9.1	9497[3]	22.9[1]	22.9[1]

Table 3 - Gradeability of 6x4 truck with three axle longs trailer

FUEL CONSUMPTION TRIALS

Background

The rolling resistance of a logging truck's tyres has been identified as the second largest energy loss (after engine friction) contributing to fuel consumption (Ljubic, 1982). The tyre inflation pressure has a strong impact on the magnitude of the rolling resistance.

On a sealed road the rolling resistance, and thus fuel consumption, decreases with increasing tyre pressure. The results of tests conducted by FERIC indicate however, there may be an optimum tyre pressure to minimise rolling resistance on unsealed roads, at lower than normal highway pressures (Ljubic, 1985). On a hard dry gravel road, Ljubic found the optimum pressure was 690 kPa (100 psi), and tyre pressures increased or decreased from this level led to increased rolling resistance.

On soft unsurfaced roads, the tyres sink into the road surface, which will result in increased rolling resistance. Lowering the tyre pressures

[1] Gradeability has been adjusted for slight grade on the test road

[2] Gradeability was reduced to 5.8% at 310 kPa tyre pressure

[3] Drawbar pull was slightly lower at 40 psi (= 9410 kg)

on soft road surfaces decreases the contact pressure, which will reduce the sinkage, and therefore reduce the rolling resistance and fuel consumption. Lowering tyre pressures will also decrease the slip on unsurfaced roads, which reduces the wasted energy input into the road surface, and thus help to reduce fuel consumption and road damage (Della-Moretta, 1984).

A CTI system will allow the tyres to be operated at the appropriate pressure for different road surfaces. LIRO has conducted two preliminary trials to determine the extent to which operating logging trucks at low tyre pressures through CTI will affect their fuel consumption.

Test Procedure - Trial One

Tests were conducted around a 4.7 km test circuit in Kinleith Forest with the CTI 8x4 truck. The road surface of the test circuit was bare pumice soil in dry condition. For these tests the pressure was altered in the driving tyres only, with all other tyres at approximately 690 kPa (100 psi). Three circuits of the road were made at each of five tyre pressures, 725, 621, 518, 414, and 310 kPa (105, 90, 75, 60, and 45 psi). The truck was loaded to a gross weight of 49,600 kg. During the tests, the driver maintained a constant speed in sixth gear. For each circuit of the road, the fuel consumption and the time taken were recorded. The fuel consumption was measured using DZL fuel meters.

Test Results - Trial One

The results from these tests are shown in Figure 3. The fuel consumption is plotted against the measured tyre deflection. A clear trend of increasing fuel consumption with the increasing tyre deflection can be seen. At 320 kPa (45 psi) tyre pressure, the fuel consumption was 0.93 litres/km, an increase of 5.6% relative to the fuel consumption at a tyre pressure of 725 kPa (105 psi). At 20% tyre deflection, which is the deflection commonly used in CTI applications, the increase in fuel consumption was approximately 4.0%. The mean speed over all the tests was 34.0 km/h, ranging from 33.8 km/h to 34.5 km/h.

Test Procedure - Trial Two

In addition to these specific fuel consumption tests, the fuel consumption of the CTI truck was measured during a CTI road impact trial in Kinleith Forest. For these tests,the pressure was reduced in all tyres on the truck. For the high pressure operation the tyre pressures were approximately 720 kPa (104 psi) on the truck and 770 kPa (112 psi) on the trailer, giving tyre deflections of around 10%. For the low pressure operation, the tyres on the steering axles were deflated to 483 kPa (70 psi) and all the other tyres were deflated to 414 kPa (60 psi). These pressures gave tyre deflections of approximately 15%. The gross weight of the truck was 44,000 kg. The truck was driven up and down an 800m section of road, and a side road was used to back around at either end. The road used for the test was surfaced with gravel on a clay base and was dry and hard packed at the time of the test, with average CBR[4] readings of over 30.

Test Results - Trial Two

For the 53 passes over the road at high pressure the fuel consumption averaged 0.91 litres/km. For the 27 low pressure runs a fuel consumption of 1.01 litres/km was recorded. This represents 11% greater fuel consumption at the lower tyre pressure. It was noted however, that the average time per pass for the low pressure runs was approximately 7% less than for the high pressure tests. This would have partly contributed to the increase in fuel consumption.

[4] CBR = Californian Bearing Ratio

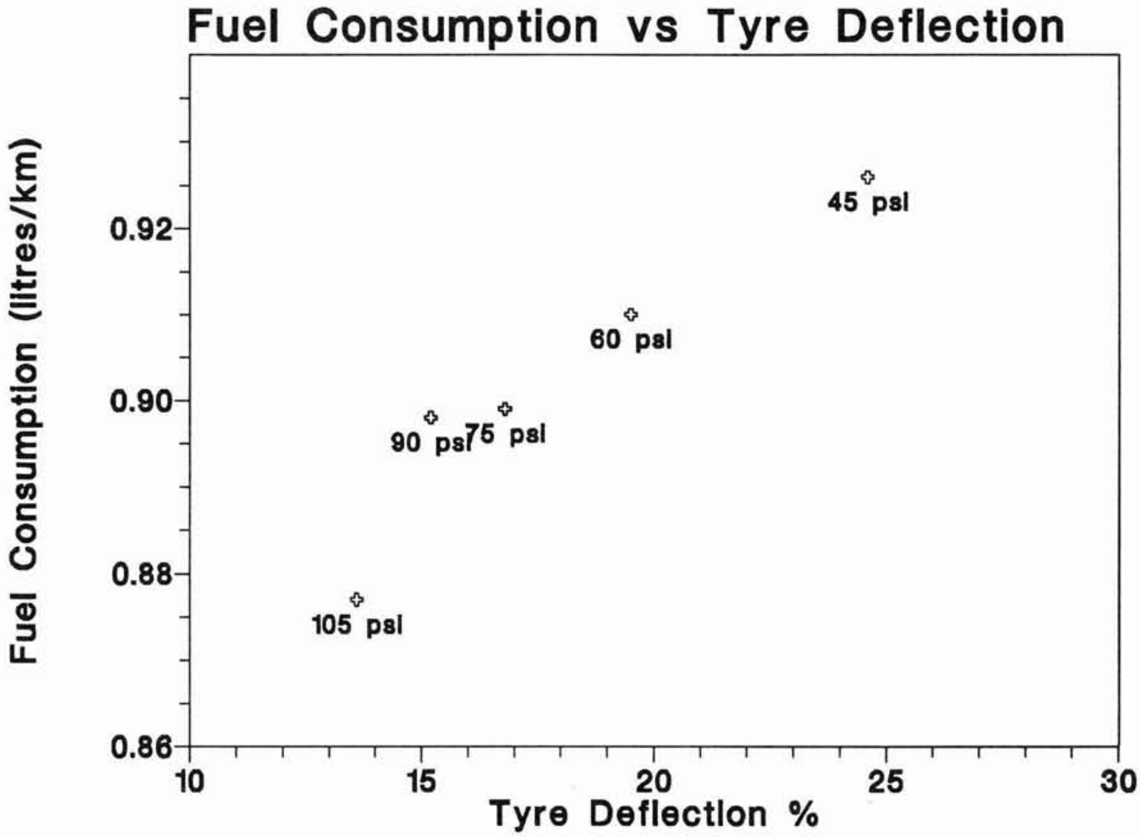

Figure 3 - Fuel consumption versus tyre deflection

Discussion

Tests by FERIC predicted an increase in fuel consumption of 8% for a change in tyre pressures from 690 kPa (100 psi) to 552 kPa (80 psi) at a steady speed of 60 km/h on a hard, dry gravel road (Ljubic, 1985). This figure supports the general magnitude of the measured result in these tests.

The results from these tests indicate that the fuel consumption penalty of operating all tyres at low pressure will be of the order of 10%. As the roads on which the fuel consumption was measured were fairly hard, it would be expected that the penalty would decrease on softer roads where low tyre pressures would most commonly be used.

Given that for most hauls only part of the total distance is off-road, CTI equipped trucks would therefore suffer increased fuel consumption on only part of the journey. Assuming the fuel cost is 14% of the total truck operating and owning costs (Goldsack, 1988), an increase of 10% in fuel consumption over 25% of the haul distance will increase total haul cost by only 0.35%. Although the benefits of low pressure tyres apply to only part of the journey, the CTI system is required to reinflate the tyres to pressures appropriate to the rest of the journey. The effect on fuel consumption would need to be investigated for the particular conditions of any proposed use of CTI.

CTI SYSTEM REPAIRS AND MAINTENANCE

For the period April to September, 1991, records were kept of the time lost due to breakdowns, and the time spent in general repairs and maintenance of the CTI system (Table 4).

Time lost to Breakdowns	14.25 hrs
General Repairs and Maintenance	14 hrs

Table 4 - Lost time due to the CTI system over a six month period

The time lost to breakdown was mainly caused by damage to air hose fittings and to the external hoses, resulting in air leaks. The general repairs and maintenance was either making permanent repairs to patch up repairs that had been made in the field, or basic preventative maintenance. Time spent in developing the system and making modifications is not included in these figures.

TYRE LIFE AND WEAR

Four new and four recapped tyres (Bridgestone 11R22.5 L301) were fitted to the drive wheels of the CTI truck and used in conjunction with the CTI system. The tyres were inflated and deflated regularly during daily operation and also during drawbar pull tests, etc. On occasions when the truck was stuck or adverse road conditions encountered, the tyres were deflated as low as 25 psi (170 kPa) to gain better traction.

The tyres were used until the end of their effective tread life. No apparent damage was present on any of the tyre cases and all were able to be re-capped (Table 5). While it is possible that multiple retreadability may be reduced in the long term by lowered pressure operation, tyres used in the USFS CTI trials have been recapped several times without problems (Zeally, 1990).

ROAD DAMAGE EFFECTS

The effect of lowered tyre pressures on the rate of deterioration of unsealed roads may be the single largest benefit of CTI. The lower tyre pressure leads to a larger tyre footprint on the road surface which spreads both the shear stress imposed by the driving tyres and the vertical load of the truck weight over a larger area. USFS trials have shown that lower inflation pressures can dramatically reduce the maintenance required on forest roads, and allows for reduced construction standards. LIRO has conducted two brief trials to investigate this effect on typical New Zealand forestry roads. These trials were of too short a duration to give conclusive results and this area requires further investigation.

As the effect of low tyre pressures on road deterioration will vary according to local conditions, preliminary trials should be undertaken prior to setting up CTI trucks in a particular area solely for the roading benefits.

CTI SYSTEM DEVELOPMENTS

An updated New Zealand CTI system is being developed by National Fluid Power Limited. that will include several features found desirable in the trials of the initial system. The driver will be able to programme in the tyre pressures for the three automatic pressure

Tyre Type	Distance Travelled (km)	Damage	Re-capped
Re-caps	26,572	none due to CTI operation	yes
New	29,575	none due to CTI operation	yes

Table 5 - CTI Tyre life

settings. This will enable the tyre pressures to be easily set to match the specific conditions that the truck is operating under at that time.

A pressure switch will be incorporated that closes off individual solenoid valves if the pressure drops below a preset level, thus isolating any leaking or punctured tyres automatically. An alarm will be also be incorporated to alert the driver to any loss of pressure. This feature is very important as several tyres on the CTI truck were destroyed through undetected deflation.

Larger capacity air compressors are available in New Zealand, with 0.85 m^3/min (30 ft^3/min) suitable for direct fitment to most trucks. This will greatly reduce the inflation times over systems using the standard size compressors of approximately 0.34 m^3/min (12 ft^3/min), and will allow more practical inflation times for CTI systems where all tyres are connected and require large volumes of air.

Larger tyre valve stems and valve cores have been tested and these will allow for 110% faster deflation times, provided the rest of the system is designed to accommodate these larger air flows. On the prototype New Zealand system, deflation from 725 kPa (105 psi) to 310 kPa (45 psi) of the drive tyres only, took eight minutes.

CONCLUSIONS

The calculated gradeability of the test trucks improved with decreasing tyre pressures on all surfaces, except on the sandy clay with the 8x4 CTI truck and on the gravel road with the 6x4 truck.

From the drawbar pull tests, it has been shown that reducing tyre pressures to below that which corresponds to 20% tyre deflection will produce limited further improvement in gradeability.

Fuel consumption has been shown to increase by up to 10% when operating all tyres at low pressure on hard surfaces. Increased fuel consumption is one trade-off which must be made in order to gain other benefits from CTI.

The road trials conducted have shown that operating tyres at low pressures may reduce damage to unsealed roads.

Tyre wear and life did not appear significantly affected by operation of CTI.

Further developments are improving the practicality of CTI technology, making it more acceptable to forestry companies and log truck contractors.

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