CHAPTER III

CONSTRUCTION OF THE PROTOTYPE RUBBER-FRICTION TRACTION SYSTEM

3. 1 INTRODUCTION

The crawler tractor, equipped with the prototype rubber-friction track under investigation was initially named “Di-Pole Tractor” by the inventor (Barnard, 1989). It was based on a four-wheel drive Allis Chalmers 8070 tractor with a 141 kW engine (du Plessis, 1996). Compared to the popularly used Caterpillar Challenger tractors, the prototype crawler under investigation had a common feature, namely the rubber contact surface with the terrain. However, the thrust generating rationale for the prototype crawler was based on friction, whilst the Caterpillar Challengers was based on soil shear. In addition to the advantages of the rubber contact surface with the ground, the prototype track system also had as features:

- rubber-covered track elements, linked by five parallel cable loops forming each of the two tracks as articulated walking beams;
- a friction drive between the pneumatic drive wheels and the track and between the track and the terrain surface;
- track tension adjusted by horizontally mounted hydraulic cylinders on the track suspension;
- a steering control system with automatic differential lock;
- two ground wheels at the centre of each track, applying a vertical force to ease the steering operation;
- achieving pivot steering about its own vertical axis; and
- considerably reduced specific ground pressure for this prototype tractor in comparison to a similar wheeled tractor.

Some comparative performance test results between the Di-Pole and conventional four-wheel drive tractors are given in Table 3.1.

Table 3.1 Comparative test results for the prototype Di-Pole and conventional Allis Chalmers 8070 four-wheel drive tractor on sandy soil (Barnard, 1989).

Tractor Type	Tractor speed (km/h)	Drawbar pull (kN)	Implement width (tilled) (m)	Cultivation rate		Diesel consumption	
				(h/ha)	(ha/h)	(l/h)	(l/ha)
Di-Pole AC Conventional	6.5 6.5	39 31	2.45 1.94	0.63 0.79	1.59 1.26	37 29	23.38 22.95
Di-Pole AC Conventional	5.5 5.5	55 43	4.12 3.22	0.44 0.56	2.27 1.77	41 31	18.11 17.51
Di-Pole AC Conventional	4.25 4.25	74 55	10.10 7.51	0.23 0.31	4.29 3.19	41 32	9.55 10.03
Di-Pole AC Conventional	3.2 3.2	105 62	16.24 9.59	0.19 0.32	5.20 3.07	41.5 29	7.98 9.45

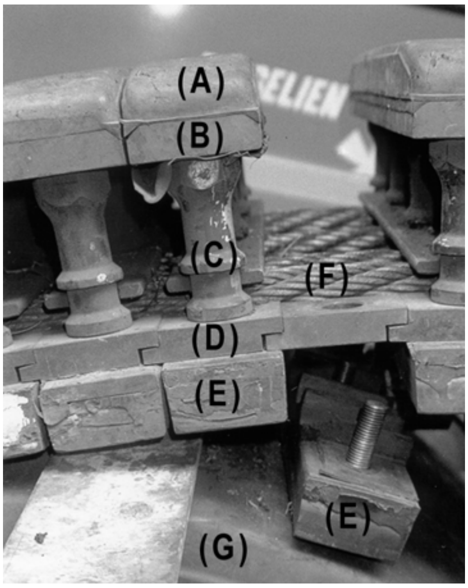
The above test results proved that under comparable conditions, the modified crawler with rubber-covered track elements had a much higher drawbar pull and working rate when compared to the original conventional tractor using the same engine. With higher drawbar pull, the engine for the modified crawler was better loaded with a higher torque applied to the tracks and therefore, the total fuel consumption in liter per hour was higher, but almost the same in liter per hectare. At lower speeds, the slip losses probably influenced the total fuel consumption for the conventional four-wheel drive tractor negatively, resulting in higher fuel consumption in liter per hectare. Unfortunately, no values of slip versus pull were supplied in the report. Although the comparison may scientifically be questionable, Barnard (1989) intended a comparison under typical farm conditions.

In this Chapter, the technical and constructional features of the prototype track, as tested on the modified tractor, will be described.

3.2 THE PROTOTYPE TRACK

3.2.1 The fundamental construction and layout

As the basic component of the track, each track element has a steel base plate (B) with a rubber pad (A) bonded to it (Figure 3.1).



(A) rubber pad to form track surface (B) steel base plate to carry rubber pad
(C) steel stud (D) steel plate carried by steel cables
(E) inner rubber pad to form inner friction surface
(E) replaceable inner rubber pad and its steel plate (F) steel loop cables
(G) rubber tyre

Figure 3.1. The fundamental components of the prototype track.

In practice, it proved that the structure of the track element was robust enough as the rubber pad never got detached during the durability tests. The steel base plates (D) fixed to the track element by studs (C) are kept in position by five steel cable loops (F). The inner rubber pad (E) is bonded to a thinner steel plate, and is linked by a bolt through the holes to steel plate (D) and threaded into the centre of the steel column (C). By rotating the column (C), the track element (A) together with (B) and the rubber pad (E) can be separated from the base plate (D).

Figure 3.2 shows an individual rubber-covered track element removed from the track assembly. As the track is composed of 101 individual track elements, instead of an integral belt, as used by other rubber tracks, any track element can be replaced individually within a reasonable breakdown time. The track therefore need not be replaced as a complete unit when partially damaged.

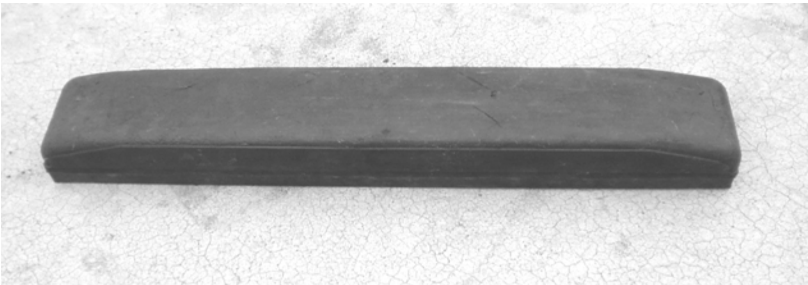


Figure 3.2. The individual track element.

Figure 3.3 shows the side view of the tractor equipped with the track. Two double rear wheels (Figure 3.3 (A)) with smooth pneumatic biasply tyres are fixed to the rear drive shafts on each side to provide rear wheel propulsion by frictional contact with the rubber-covered inner surface of the track. In comparison to the active drive, this frictional drive automatically protects the mechanical system against overload. Unfortunately, slipping losses may be caused by decreased track tension and propulsion force when the tractive load is high or the frictional properties deteriorates, caused by operational circumstances such as heat, water, soil or other foreign inclusions. It was found from the initial tests that the slip was increased by low track tension.

To prevent damage at the interference by mud entering the friction surface, the friction drive periphery of the prototype track is positioned 200mm above the ground level. The height of the track elements and the rubber pad (Figure 3.3) lifts the internal rubber frictional surface of the track well above ground level, making it less susceptible to inclusion of foreign material like mud at the driving surface. This also prevents a bulldozing effect occurring when steering.

(A) Rubber tyre (B) Centre ground wheel (C) Dividing flanges
(D) Swinging axle mounting (E) Hydraulic ram adjusting the track tension
(F) Locking device

Figure 3.3. Side view of the prototype track fitted to the tractor.

3.2.2 The centre ground wheels

Hydraulically activated centre ground wheels (Figure 3.3 (B)), with solid rubber tyres, can be lifted or pushed down when necessary. During steering, the centre ground wheels are forced against the lower portion of the track so as to increase the curvature of the track and thus decrease the contact area. Pivot steering is approached by the two wheels on each side, fixed to a single axle. For sharp turns, when one track was driven forwards and the other rearwards with the centre wheels pushed down onto the tracks, tractor turned along in a circular path around the vertical axis of the tractor with minimal damage to the soil surface.

Under normal operational conditions for straight line travel, the centre wheels (B) may be moderately pushed down onto the track to help achieve a more evenly distributed ground contact pressure. However, this was not the original design purpose of the centre wheels.

3.2.3 Track mounting, tensioning and driving friction at interface

The tracks are carried by two vertically swinging axle mountings (Figure 3.3 (D)) pivoted around the original rear axle extensions with the cranks loaded by rubber springs at the front. This facilitates the use of the original tractor T-frame for mounting the two track assembly units on to the original frame of either side shaft, without necessitating any changes to the existing drive system. Frictional propulsion is generated by contact of the flat-treaded pneumatic tyres (Figure 3.3 (A)) with the inner track elements consisting of compression–molded composite of a carboxylated nitrite.

The track is laterally constrained by dividing flanges (Figure 3.3 (C)) at the centre of the inner track surface fitting into the gap formed between the side walls of the two pneumatic drive wheels and the two pneumatic tensioning wheels.

By extending the centre distance between the driving wheels and the driven wheels by means of permanently mounted hydraulic rams (Figure 3.3 (E)), the track tension necessary for the driving friction can be set by applying the correct pressure to the tension cylinders. The mechanical locking device (Figure 3.3 (F)) maintains the tension during normal operation. However after several hours of use, it may lose grip and must be retensioned. The frictional propulsion of the track is also assisted by the deflection of the tyre side walls clamping the central dividing flanges (C) when the tyre side walls are deflected outwards by the vertical load.

3.2.4 The beam effect

In order to achieve the so called “walking beam effect”, the track elements were designed with dimensions A<B<C<D as shown in Figure 3.4. It was claimed to function in a way that when a series of wedge-shaped track elements were linked by the five close loop cables, an oval shape, as seen from side, was formed by the track. The curvature of the upper and lower portions of the track is therefore obtained from the slightly wedged shape of the track elements, extending outwards beyond the inner peripheries of the steel cables. The lower free span of the track in contact with the soil behaved like a compound beam, stressed by the mass of the tractor. The radius of the ground contact arc depended on the load and according to the designer varied between about 30 meters and infinity, but the claim was not proofed. The elastic resistance of the straightened track was expected to provide a more uniform pressure distribution underneath the track than for a conventional flexible rubber track supported only by road wheels.

As reported by du Plessis (1996), the walking beam effect was reduced, probably due to cable strain and wear on the contact surfaces between track elements. During tests flat metal spacers were inserted between the track elements to restore the beam effect, but they were soon damaged (Figure 3.4 (E)) and the beam effect was lost again.

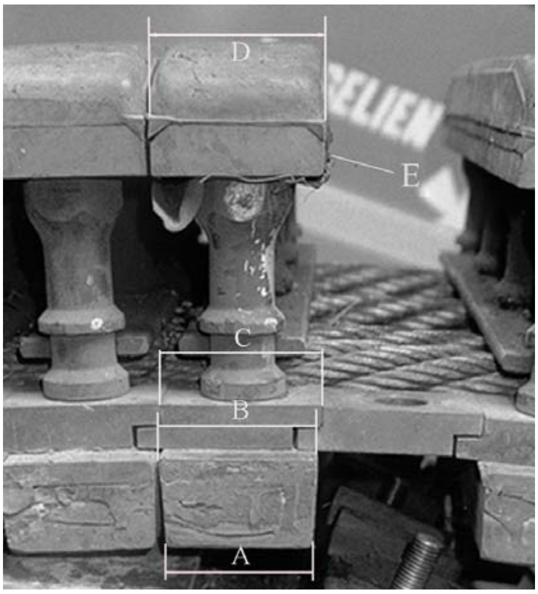


Figure 3.4. The wedge-shaped track elements to enable the beam effect.

3.3 THE DRIVE TRAIN, STEERING CONTROL AND AUTOMATIC DIFFERENTIAL LOCK

The patented drivetrain featured with the automatic differential lock, the differential steering system and the swing mounted track carriers constitute an important part of the design. The schematic layout of the drive train of the tractor, equipped with the prototype track, is shown in Figure 3.5 (du Plessis, 1996).

The control differential (S) consisted of nitride spur gears, driven by the input shafts K_1 and K_2 (Figure 3.5a). The input ring gear (R) is mounted around a circular cage (K) and a pair of half shafts (H_1 and H_2) with spur gears (R_1 and R_2) (Figure 3.5 b) at their inner ends. Spur pinions (A) are provided as two identical pairs in a diametrically opposite arrangement on a pitch circle about the half shafts H_1 and H_2. The spur pinions (A) are meshed with the spur gears (R_1 and R_2) and with each other.

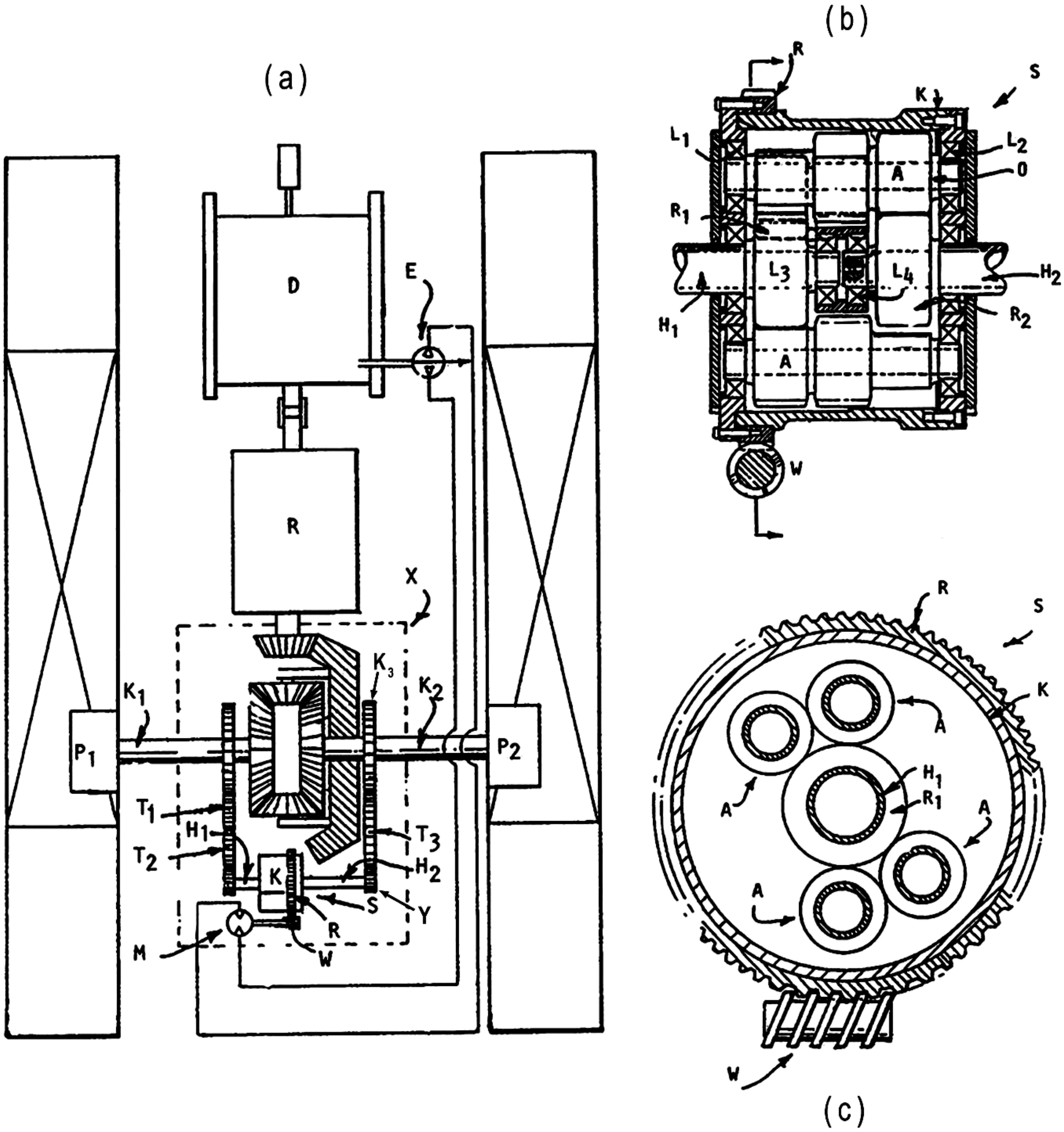


Figure 3.5. The drive train and the differential lock.

In the control differential (S), the half shafts (K_1) and (H_1) are interconnected by spur pinions (T_1) and (T_2) to accommodate the distance between the shafts. Spur gear (K_3) is fixed to the half shaft (K_2) and spur pinion (Y) is fixed to the half shaft (H_2) with idler gear (T_3) to form a gear train driving (K_2) and (H_2) in the same direction. With a gear ratio of about 6:1 the shafts (H_1 and H_2) rotate in opposite directions at a speed six times that of K_1 and K_2, thus reducing the shaft diameter and mass.

For straight line travel the half shafts (K_1) and (K_2) rotate at the same speed and direction and the spur pinion (A_1) and (A_2) in an opposite direction at equal but a higher speed, but at zero torque. They do not orbit and the ring gear (R) is stationary. The spur pinions are driven by (H_1) and (H_2), but are also interlocked as shown on the end views and the differential is automatically locked.

When steering, the variable displacement hydraulic piston pump (E), and the motor (M) drives the control differential via a worm gear (W) in a desired direction and speed, corresponding to the steering angle. The force from the inside track is thus transferred to the outside track via the control differential (S) and regeneration takes place. One track may even move forward and the other rearwards.

With an asymmetrical resistance, one track would tend to slow down and the other to speed up, due to differential operation. This unequal torque tends to rotate the differential (S), the ring gear (R), gear (W) and the motor (M). With a closed hydraulic valve, or a worm gear (W) with a speed ratio of at least 6:1, the control differential is locked and unstable steering action is thus prevented.

For straight travel, the spur pinions (A) spin at a high speed and conventional differentials with bevel gears are not suitable. Contrary to the standard cantilever arrangement, the spur pinions (A) are also supported on either side by bearings (L_3 and L_4). Large diameter thin-walled hollow shafts (H_1 and H_2) are used to enhance the load carrying capacity and resilience with minimal inertia.

The design features as explained enable regeneration and replace complex devices such as a null shaft.

3.4 DIMENSIONS OF THE PROTOTYPE TRACK

Based on the original design, the relevant dimensions of the track are shown in Figure 3.6. The distance between the front and the rear axles can be adjusted up to 2000 mm at maximum by hydraulic cylinder (E) as shown in Figure 3.3.

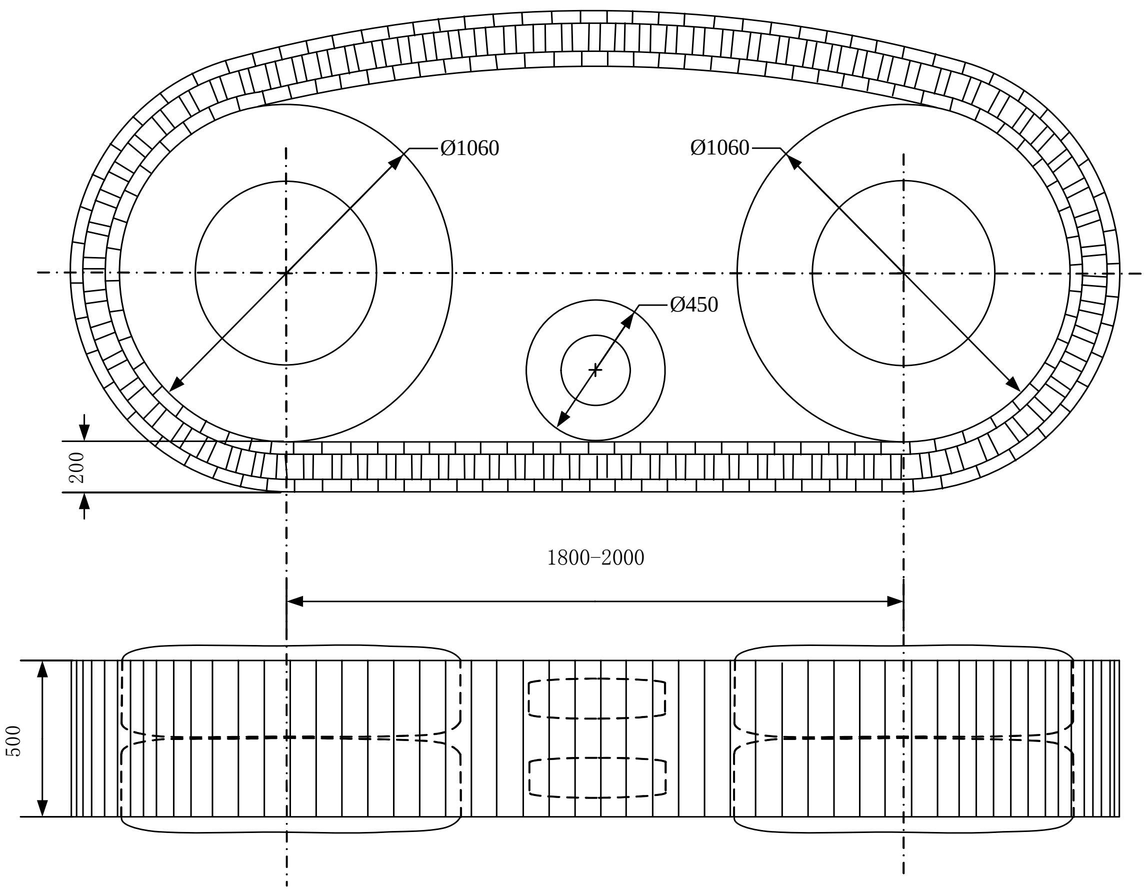


Figure 3.6. The dimensions of the prototype track.

3.5 PRELIMINARY TESTS AND ASSESMENT OF TRACTIVE PERFORMANCE

Tests carried out to evaluate the handling and performance characteristics of the prototype track system were reported by du Plessis (1996). The test results for this field performance evaluation are shown in Table 3.2. The engine for the wheeled tractor was used and the crawler had a new engine, thus the dynamometer measured power for the two engines were slightly different.

Table 3.2. The comparative test results for the prototype crawler and a four-wheel drive tractor (du Plessis, 1996).

Type	Conventional four-wheel drive tractor (used Allis Chalmers 8070)	Di-Pole crawler (Based on new Allis Chalmers 8070 tractor)
Engine power tests		
Maximum engine power (kW)	132kW@2400rpm	141kW@2400rpm
Maximum torque (Nm)	600Nm@1800rpm	645Nm@1800rpm
Test on a soft surface		
Gear for maximum power	4 Low	4 Low
Maximum drawbar power (kW)	58	63
Drawbar pull (kN)	31	53
Speed (km/h)	6.8	4.3
Rolling resistance (kN)	9	14
Wheel or track/soil slip (%)	Front 19.0, rear 21	5.9
Slip between drive wheels and track (%)	-	9.4
Test on a concrete surface		
Gear	4 Low	4 Low
Maximum drawbar power (kW)	77	79
Drawbar pull (kN)	38	55
Speed (km/h)	7.3	5.2
Rolling resistance (kN)	8	9.5
Wheel or track/road slip (%)	Front 4.7, rear 4.4	1.0
Slip between drive wheels and track (%)	-	3.4

The engine for the conventional four-wheel drive tractor was used whilst that for the crawler was new, thus the difference in power existed. The results showed that on both a concrete and a soft surface, most of the performance characteristics for the prototype crawler were superior to that of the conventional four-wheel drive tractor equipped with a similar specification, but used engine. Particularly for the test on a soft surface, the slip of the crawler tractor was at 5.9% whilst the wheeled tractor at 20%. However, the rolling resistance for the crawler was higher than for the standard four-wheel drive tractor for both hard and soft surfaces. The friction between the track and the drive wheels for the crawler was another factor which influenced the performance of the crawler negatively. The distribution of the contact pressure as observed was uneven and the beam effect, as was envisaged by the original design, did not materialize (du Plessis, 1996).

3.6 SUMMARY AND REMARKS

Based on the description of the design and construction in this chapter, it is shown that the prototype crawler featured with the friction-based track and the patented drive train system is uniquely distinct from other wheeled tractors or crawlers currently in use. Theoretical traction performance modelling had not been carried out for such a tractor. The assessment of factors influencing the traction performance would also be of interest. Therefore, the following conclusions were drawn:

- The rubber-rubber and rubber-terrain friction-based track played an important role in distinguishing the prototype crawler from other tractors.

- The drive train including the automatic differential lock performed well.

- More specialized tests needed to be conducted if the tractive performance of the track was to be evaluated or validated by modelling.

- The walking beam effect could be restored partly by means of inserting some flat metal sheet spacers between track elements to restore the outer circular length of the track. However, they were soon damaged and the beam effect was lost again.