TRACTORS AND TRANSPORT VEHICLES

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Contents

Summary

Tractors, central to mechanization, developed since 1769 with the invention of the steam engine to the present sophisticated agricultural tractor. Modern state-of-the-art technology and computer-based electronic systems, will in future be used on a larger scale to link up with the global positioning system (GPS) to provide automatic steering and speed control necessary for optimization and precision farming.

The diesel engine will probably remain the main source of tillage power. Cleaner burning alternative renewable fuels with less harmful effects to the environment may partly replace diesel as sources of energy for cultivation and mechanization in the future.

The direct application of grid electricity or alternative power reservoirs like batteries are at present not yet viable in 2000. New technology may improve the energy density and cost of batteries to be used for tractors. Tractor mass is however, not as critical as for transport or passenger vehicles.

The tractor with its drawbar will, in future, probably remain the main source of energy for cultivation. More emphasis will, however, be placed on ergonomics and a safer and

more comfortable operator cab. Computerization to optimize the developed engine power, the efficient transmission of energy via drive systems, and especially the traction system will see much development. On-board computer modeling will also assist with the optimum matching of implements and tractors.

The future farmer will produce enough high-quality healthy food on a sustainable basis with minimum impact on natural resources through increased efficiency, allowing a larger percentage of the population to be employed outside the food and fiber producing sector with more time available for a healthy and quality life style.

1. Mechanization, Tractor Development, and Tractor Performance

In the early 1900s, a large proportion of the world population lived on farms. Productivity increased almost exponentially and in the USA, for example, $<5\%$ of the population in 2000 are farmers. In most other countries, this percentage is still considerably higher.

1.1. Mechanization and Tractors

Tractors are central to mechanization to reduce the drudgery of farm work, increase productivity of farm workers, and improve timelines and quality of farm work and cultivation.

An adult human produces energy equivalent to a diesel consumption of $\pm$ 0.05 L h^{-1} while working continuously. For diesel fuel at US\$1.00 L^{-1}, this is worth only US\$0.05 h^{-1}. Even at higher fuel prices and all costs included, this value remains insignificant.

Currently, farmers with high-capacity machines perform critical operations in a timely fashion to accomplish maximum yields, thus allowing the population time for other occupations. This trend will probably continue in the future, but mechanization must remain appropriate and affordable.

1.2. The Development of the Agricultural Tractor

James Watt patented his steam engine in 1769. Since the 1870s, inventors have applied these principles to build self-propelled steam tractors, mainly for plowing and driving threshing machines.The German inventor Dr. Nikolaus Otto applied the principles formulated by Beau de Rochas and with Engen Lange built a so-called Otto cycle (spark ignition) engine comprising an intake, compression, ignition by a spark, power, and exhaust stroke, still used today. Dr. Rudolph Diesel patented his cycle using fuel ignited by heat produced during compression. His engine was the first to stem from thermodynamic theory rather than innovative technology.

Since about 1890, tractors with internal combustion engines were manufactured in competition with steam traction engines. Steam engines lost popularity since the Winnipeg trials of 1908–1912 and smaller, lighter, general-purpose tractors became popular from the 1920s.

Pneumatic tires replaced steel wheels and the three-point hitch was introduced in the 1930s. The 1940s and 1950s brought hydraulic systems, self-starters, and better seating. Power steering, independent power take-off (pto), and the power-shift transmission were introduced in the 1950s. Alternators, turbochargers, and hydrostatic transmissions were introduced in the 1960s and four-wheel drive (4WD) in the 1970s.

Since 1990, improvements have included larger wheel diameters, high-speed tractors (40 km h^{-1}) with suspensions and brakes on both axles, transmissions with more ratios and power-shift versions, additional power take-off (pto) speeds with front hitch and front pto, more advanced hydraulic control systems, safer and more comfortable cabs, and computer-controlled network. Turbochargers and intercoolers are now even used for smaller four-cylinder engines.

1.3. Tractor Types

Tractors, originally used mainly for plowing and threshing, were soon replaced by general-purpose row-crop models. The tricycle configuration of the 1940s was replaced by center-pivoted wide front axles (Figure 1) and special orchard models with a narrow wheel spacing were introduced.

Figure 1. Standard row-crop tractor with wide front axle
Photo by Tingmin Yu

Crawlers were also used on farms since the 1920s but were soon replaced by large 4WD tractors. Recently, the belted agricultural tractor, combining the benefits of low ground pressure and high drawbar pull with the mobility and better ride quality of wheel tractors, were introduced.

Row-crop tractors were also equipped with optional front wheel drives (Figure 2). Four-wheel-drive tractors with four, six, or eight wheels and articulated steering are at present common for heavy draft applications. A rigid tractor frame with front, rear, or crab steering is also possible.

Figure 2. Two-wheel-drive tractor with optional mechanical front-wheel assist
Photo by Tingmin Yu

1.4. Future Development of Tractors

Drawbar pull can be increased by more massive tractors or increased tractive efficiency by optimizing tires or using rubber belts (caterpillar) or other prototype tracks (Figure 3).

As purchase cost is related to mass, the tendency is towards higher power-to-mass ratios, necessitating increased tractor speeds to utilize the available power. Without new technology (e.g., computer control producing increased pull/mass ratios), the upward trend in drawbar power will level off. With microprocessors, the gear ratio for optimum engine efficiency can be selected, and developments in automation and on-board computers will be part of future technology.

Figure 3. A prototype drive system and track developed by Dr. Jan Barnard
Photo by Tingmin Yu

In Europe, tractors for special applications—the "Euro-Trac" and mid cab "Zylon" or high-speed tractor (40 km h^{-1}) for road use by JVC, Carrero, and Deutz—are available but the "standard tractor" with smaller driven front wheels (Figure 2) will probably remain the leading concept.

Engine design may be altered by using ceramic parts, allowing higher operational temperatures and thermal efficiencies. Multifueled engines may also be introduced to use any readily available fuels.

1.5. Concepts of Force, Torque, Work, and Power for Tractors

Force in Newtons (N) is the action of one object on another to move it or change its shape. A torque attempts to cause rotation about a point; for example, a wrench tightening a bolt.

Torque = Force (N) × perpendicular distance to the line of action (m) = Nm = Joule (J).

Work is accomplished when the point of application of a force moves in the direction of the force. The work is the product of the component of the force in the direction of movement and the distance through which the point of application moves (Figure 4).

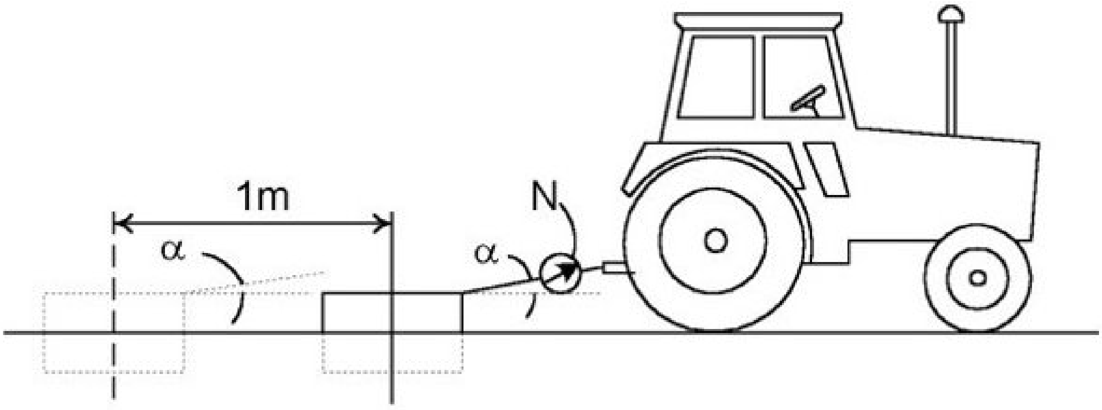

Figure 4. A tractor pulling an implement accomplishing work.

When a tractor pulls an implement for a distance (d) meters with drawbar pull (y):

Work = y N× cos α × d m = x J

where α = pulling angle. Power is a rate of doing work. If, for an effective force of 1 N, the implement moves in the direction of the force through a distance 1 m in 1 s:

Tractor drawbar power = 1 Nm s^{-1} = 1 Watt (W).

If one kilowatt (kW) is applied for one hour the result is:
Work = 1000 W × 60 s × 60 s h^{-1} × s = 3.6×10^6 Nm or Joule (J)

The equivalent fuel power (P_{fe}) is valid for 100% efficient combustion without heat loss:
P_{fe} = heat value of the fuel (J kg^{-1}) × fuel consumption (kg s^{-1}) = Watts (W)

The indicated power (P_i) is calculated from the mean effective pressure (P_a, N m^{-2}) originating from the pressure displacement diagram, piston area (A, m^2), stroke length (L, m) and power strokes per second (X). Due to friction losses and etc., only some of this power is available at the crankshaft.

For an engine with n pistons, the indicated power (P_i) = $P_a \times A \times L \times X \times n$(W).

The brake power (P_b) is measured by a brake dynamometer at the engine crankshaft with none, some or all accessories stripped and with a throttle fully open at rated speed.

The simplest type of brake, the Prony dynamometer (Figure 5) consists of blocks clamped by the knob (1) around the crankshaft or flywheel (4), rotating at (n) revolutions per second, creating a torque on the drum measured as the force in (F) Newtons by a scale (2), located at the end of the arm (3) of length (ℓ) in meters. The dynamometer must be cooled.

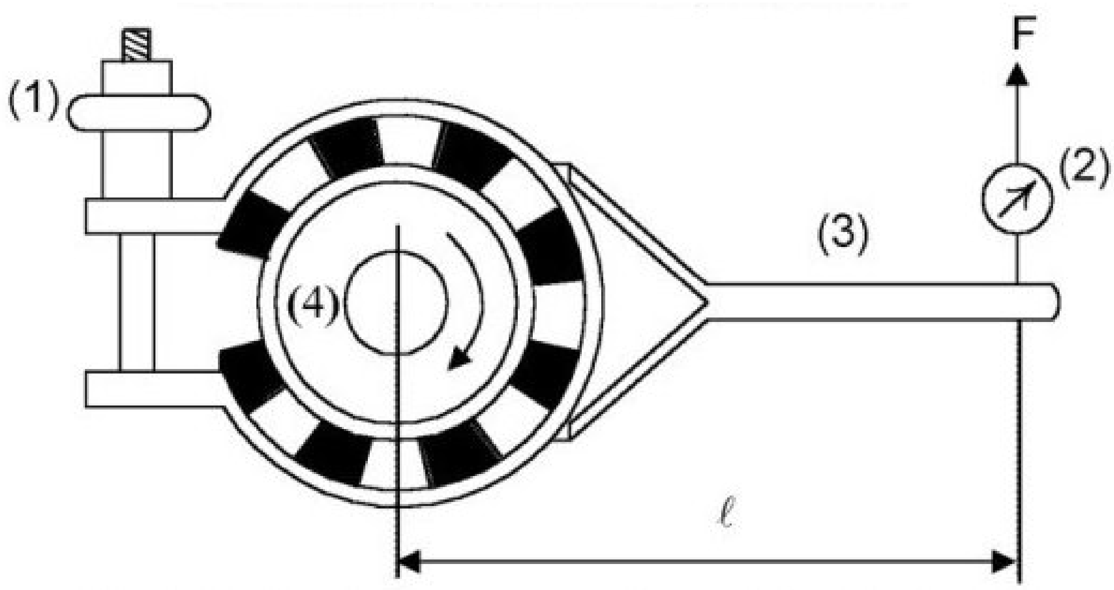

Figure 5. The Prony brake dynamometer
Courtesy University of Pretoria

Power (P_b) $= (2x\overline{\Pi}x\ell xFxn)/1000 = \omega T/1000$ with $\omega = 2\pi n$ and torque (T) = $F \times \ell$

The brake power is affected by the temperature of the intake air and altitude. The observed brake power must be corrected to standard atmospheric conditions (1.013 Pa and 15.5 °C) and zero vapor pressure. Turbocharging decreases power losses at high altitudes.

Engine friction power as measured by a transmission dynamometer, is the power required to run the engine at a given speed without producing useful work and represents friction and engine pumping losses.

Friction power = indicated power (P_i) - brake power (P_b)

The belt power, measured by an absorption dynamometer at the end of a suitable belt, is less than the brake power due to gearbox losses and belt slip.

The drawbar power is the rate of work of a tractor when pulling a load with the drawbar.

Drawbar power = effective force (N) × true speed V_a (m s^{-1}) = Nm s^{-1} = Watt (W)

The pto power is available at the power take-off shaft (pto), usually as measured by an absorption dynamometer. It is less than brake power but greater than belt power.

The rated power is based on the maximum brake power. Belt power = ± 85% and drawbar power = 75% of the maximum brake power to prevent damage in continuous operation.

1.6. Performance Criteria for Tractor Engines

Diesel engines used in tractors or trucks typically convert <40% of the fuel energy into useful mechanical power and can be evaluated by the following formulae:

Indicated thermal efficiency (η_{it}) is the fraction (in percent) of the fuel-equivalent power converted to indicated power (η_{it}) = 100 × $P_i P_{fe}^{-1}$

Mechanical efficiency (η_m) = 100 × $P_b P_i^{-1}$ = brake power/indicated power × 100, and varies from 75 to 90%.

Thermal efficiency (η_{th}) = 100 × $P_b P_{fe}^{-1}$ and indicates the total efficiency of converting fuel to useful power. For carburetor and diesel engines, it is typically ± 25–30% and ± 33–40%, respectively.

The specific fuel consumption in kWh L^{-1} or kWh g^{-1} is calculated from the recorded fuel consumption in g s^{-1} or mL s^{-1} and engine power in kilowatt (kW).

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Bibliography

Goering C.E. (1992). *Engine and Tractor Power*. 3rd Edition. 539 pp. St. Joseph, Michigan: American Society of Agricultural Engineers. [This is a comprehensive text book on engines and tractors.]

Holloway G.A. (1987). The environment of electrical/electronic components on agricultural equipment. *ASAE Distinguished Lecture Series No. 12.* 16 pp. St. Joseph, Michigan: American Society of Agricultural Engineers. [This design lecture explains the application of electrical and electronic systems in agricultural equipment.]

Liljedahl J.B., Turnquist P.K., Smith D.W., and Hoki M. (1996). *Tractors and their Power Units*: 4th Edition. 463 pp. St. Joseph, Michigan: American Society of Agricultural Engineers. [This is a comprehensive textbook on engines and tractors.]

Prick W.L. and Becker T.H. (1985). The application and installation of diesel engines in agricultural equipment. *ASAE Distinguished Lecture Series No. 11.* 24 pp. St. Joseph, Michigan: American Society of Agricultural Engineers. [A discussion on the installation of diesel engines in agricultural equipment.]

Renius K. T. (1994). Trends in tractor design with particular reference to Europe. *Journal of Agricultural Engineering Research* **57**, pp. 3-22. [An analysis of tractor design trends in Europe.]

Söhne W. (1976). Terramechanics and its influence on the concepts of tractors, tractor power development, and energy consumption. *Journal of Terramechanics*, **13**(1), 27–43.

University of Pretoria (1999). Unpublished lectures on Farm Power and Machinery. 250 pp. Pretoria, South Africa. [This is a set of lectures with drawings for farm power and machinery.]

van Straelen B.C.P.M. (1975). Braking of Agricultural Trailers. *Publication of Instituut voor*

Mechanisatie, Arbeid en Gebouwen. 40 pp Wageningen, The Netherlands. (Publication of the Institute for Mechanization, Labor and Buildings, Wageningen. In Dutch with English Summary). [A theoretical analysis and practical tests for trailer brakes].

Wittren R.A. (1975). Power steering for agricultural tractors. *ASAE Distinguished Lecture Series No. 1.* 50 pp. St. Joseph, Michigan: American Society of Agricultural Engineers. [A lecture on the design and application of power steerings.]

Wong J.Y. (1989). *Terramechanics and off-road-vehicles.* 251 pp. Amsterdam: Elsevier. [This is a comprehensive discussion on soil dynamics for off-road-vehicles.]

Biographical Sketch

Hendrik Lourens Marthinus Du Plessis was born on 20 May 1942 and matriculated in 1959 at the Afrikaanse Hoër Seunskool. Pretoria. He was awarded a BSc (Eng)(Agric) in 1963 and a MSc (Eng)(Agric) in 1972 by the University of Pretoria. From 1981 Prof. du Plessis consulted for the Laboratory of Advanced Engineering. Based on a research project undertaken for the laboratory on tractor tires the PhD-degree was awarded to him in 1990.

As founder and associate member of the South African Institute of Agricultural Engineers, he registered as Professional Engineer in June 1969 and is at present President of the Institute.

His research interest is in soil dynamics in tillage and traction and he undertook several research projects in this field.

He is married to Ina du Plessis, a psychologist, and they have three sons. She is currently the manager of the Academic Development Program in the Faculty of Engineering.

Rennie enjoys outdoor life as a part time cattle and game farmer with an interest in the restoration of antique furniture and hobby gunsmithing.