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Developments in Tractor Design

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Abstract

Economic background is discussed with consequences for tractor industry and tractor concepts. Particular reference is given to the question of frame chassis instead of block concept. Development trends of tractor components are analyzed for driving system (including four-wheel drive and brakes), diesel engines, transmissions, human engineering, hydraulics and implement control. Consideration is given to electronics and aspects of environmental protection as well. Expected further tractor design developments are summarized at the end of the paper.

1. Economic situation

"Agricultural production has increasingly depended on the universal application of the tractor", stated Göhlich 1984 addressing the important mechanization period since about 1930 in many countries. The tractor represents today in the developed countries mostly the largest share of total agricultural machinery investment, for example 40% in Germany (1991) and 45% in Japan (1990). Annual sales in the Western world have been estimated by McKee (1992) at about 650 000 (1991), for a range of 12 to 300 kW rated engine power.

Larger farm sizes and declining numbers of farms and farmers have become typical for many highly developed countries. Joint usage of machinery as well as contracting became more popular. Both trends have resulted in larger tractors as indicated for Germany in **Fig. 1**. In Europe tractor business (in units) decreased dramatically as shown in **Table 1**. The drop is not only a consequence of bigger units, but also of reduced prices received by the farmer for his products.

In general, tractor companies in Western Europe have to face the following background trends for their business:

- Decrease in market volume
- Increase in tractor functions & options
- Increase in regulations and restrictions
- Increase in labor cost
- Increase in quality level
- Increase in international business & cooperation

All these items contrast with the price which the farmer is able and willing to pay. In order to reduce investments and other overhead costs, several tractor companies have started close cooperations such as Deutz & Same, Steyr & Valmet, Steyr & Massey Ferguson, Ford & Fiat, Same & Renault, J. Deere & Zetor etc. While they are all reducing their staff, some of them have suspended the production for limited periods. Case just decided to close down its old and well known tractor production plant in Neuss/ Germany completely in favour of the plants in the UK and USA.

In spite of such business trends, the tractor is, and will in the near future also continue to be, one of the most necessary machines of mankind. It has been shown by Heumann et al. (1980), that the available tractor power per agricultural worker is in a surprisingly good correlation with the living standard of a nation. As there is still a tremendous backlog in large areas of the world such as Asia, Africa and South America, tractor development and production will remain a subject of high priority for further decades.

2. Tractor concepts

2.1 Survey

Typical tractor concepts in Germany are demonstrated together with their market shares by **Fig. 2**. The so called "standard tractor" is clearly dominating not only in Germany but also in Europe and worldwide. Special concepts can vary in design and market share from country to country. Large articulated four-wheel drive tractors are, for example, not important in Europe, but common in North America and Australia for large farms. The author estimates that the standard tractor concept covers more than 85% of the total worldwide sales (in units) if walking tractors are excluded. In Europe, a change has taken place from rear-wheel drive to four-wheel drive, **Fig. 3**, as in principle early forecasted by Söhne (1964).

A typical European standard tractor line consists of at least three groups with three, four and six cylinder engines, **Table 2**. The four cylinder group represents the most popular one, some typical specifications for a European tractor within this group are therefore summarized by **Table 3**.

Ground drive systems of standard tractors have been equipped with unsuspended axles over some decades because of lower first cost and simplified implement guidance. A comeback of front axle suspensions could offer improved ride comfort and driving safety, as investigated by Weigelt (1987). Top speeds higher than 40 km/h are also in discussion, but will likely be restricted in the near future by an expected EEC regulation favouring 40 km/h: The author therefore sees only niche markets for suspended high speed standard tractors. Furthermore, a high speed pulling of heavy trailers requires considerably high engine power (Renius 1992a).

2.2 Frame chassis for standard tractors?

The so called "block chassis" principle with engine and transmission housing instead of a frame has been the most important rule for standard tractor design since the famous presentation of the "Fordson" tractor in 1917. There were some exceptions, as in the case of garden tractors and special vehicles such as the german "Unimog" and "MB trac" using full frames. Several standard tractors have been equipped with semi-frames, which were however in most cases added to reinforce the front part of the block. Bacher (1981) reported a considerable noise reduction potential for standard tractors, if a semi-frame is used for a suspended and well shielded engine. At the same time, front mounted implements became popular for standard tractors and the sizes of front end loaders were increased continuously. Both trends sometimes required very high efforts to achieve the necessary durability of the block structure, mainly at the engine.

Within the period of 1984 to 88, the "Munich Research Tractor" was developed, as reported by Renius (1988) and Kirste (1989). This project had been started in order to investigate the noise reduction potential of full frame concepts and the performance of infinitely variable transmissions amongst other design principles. The configuration of the frame and the power train is shown in **Fig. 4**. The diesel engine is suspended on three noise isolating elements with a flat bonnet used as a capsule with only two small passages for cooling air. The gearbox is still rigidly connected to the (conventional) rear axle, and is shaped for minimized noise emission. Bystander noise level of the complete tractor has been reduced by 11 dB(A) for an air cooled and 12 dB(A) for a water cooled engine related to the average of OECD tests carried out between 1981 and 87. Some experience with the chain drive transmission will be reported later.

In September 1992, J. Deere presented two newly designed tractor lines "6000" and "7000" using a frame concept, which is in principle similar to that of the Munich Research Tractor, **Fig. 5**.

Against this background, main advantages of frames can be seen in

- noise reduction potential
- easier maintenance & repair
- component flexibility
- easier to achieve durability for high payloads

Tractor weights can be reduced due to light weight engine, light weight gear box and easier to attach front implements and front end loader. First cost for the basic vehicle seem not to be considerably lower. Higher savings can be expected for attachment elements. Finally the advantages are of high significance, such that the author forecasts a gradual loss of importance of the old "Ford Rule".

3. Tractor components

3.1 Driving systems, steering, tyres and brakes

Not only the European but also the Japanese and some other markets favour clearly the four-wheel drive with unequal front and rear tyres. This is a consequence of significant economic benefits, which are now recognized mainly for working in soft soils and for front end loading and which have been early forecasted by Söhne (1964), Renius (1979a) and some others. Extra first costs for the drive could be reduced to only about 20% more than its two-wheel drive counterpart (Rackham 1985). A central shaft to the front axle is in principle less expensive than a lateral one. High inner steering angles up to now 55 degrees are feasable for both concepts. Open questions remain in "transmission wind ups" and the so-called "pull-in-turn" problem due to the fixed ratio between rear and front axle. The overdrive shift for the front axle in sharp turns, first introduced by Kubota in 1986, became popular for small tractors in Japan.

The recent drive tyre development in Europe is characterized by four main trends:

- Market share of radials increased to about ⅔ (1992)
- Dimensions increased more in width than in diameter
- Minimum possible inflation pressures could be reduced
- Universal concepts for field and road have clearly been preferred.

Best use of the tyre potential requires adequate adjustment of inflation pressure. Some first commercial approaches of on-the-go control have been presented in Germany. According to research results of Chung-Kee-Yeh (1992), ride comfort at speeds up to 50 km/h is much more influenced by tyre radius deviations than by unbalanced tyre masses.

Within the range of brake concepts for the rear axle, the wet disc type is becoming dominant. It is working maintenance-free at the pinion shafts of the final planetary drives. For front axle braking caliper brakes on the connecting shaft are often used in Europe because of very low first costs. Also, in several tractors the front axle is braked by the rear axle, which is achieved by automatic activation of the four-wheel drive clutch when braking.

3.2 Diesel engines and energy supply

Hundred years after the famous invention of Rudolf Diesel (German patent No. 67207, 1893), the diesel engine is and will clearly remain the standard power unit of agricultural tractors. The average engine power has been increased in Europe since the fifties by a factor of about 400%, average rated engine power of sales in Germany increased for example from 13 kW (1954) to 68 kW (1992). The author expects that this trend continues in the near future. Recent power improvements could mainly be achieved by turbo charging. Additional intercoolers are already well accepted by the farmer for six-cylinder engines, but less popular in the four-cylinder tractor group.

An important step towards higher performance of four-cylinder engines was presented 1992 by Mercedes-Benz with the new turbocharged and intercooled OM 364 for the new Unimog U140 producing 98 kW at 2400 rev/min with only 3.972 cm3 displacement. The author is convinced that such a concept is superior to naturally aspirated six-cylinder engines (of the same power) regarding weight, cost, emissions, high altitude performance, oil change volume, exhaust noise and fuel consumption and that that the Mercedes-Benz engine represents therefore an important signal.

Typical general development trends for tractor diesel engines can be summarized by two sections A and B:

A. Increased power and reduced exhaust emissions by

- Turbo charging with intercoolers
- Higher injection pressures (above 1000 bar)

- Electronic injection control
- Oxidizing catalysts (particle filters in discussion)
- Exhaust gas recirculation (EGS)

B. Improved comfort and fuel economy by

- Constant power within the upper speed range, using high torque back ups
- No torque lack at lower speeds, achieved by adequate air charge
- Automotive control strategies for on-the-road operation, possible with electronic injection control
- Reduced noise emission, achieved by design modifications, stagnating engine speeds and shielding
- Improved fuel economy, possible with optimal burning process, minimized engine friction and reduced power for auxiliary drives.

Best specific fuel consumption within the performance map should be about 200 g/kWh for four and six cylinder units. The use of vegetable oils as diesel fuel could enable a closed CO_2 circuit. Several approaches can be classified in two strategies: To adjust the fuel to existing engines (i.e. by esterified vegetable oils) or to develop engine concepts, which are able to burn unrefined rape seed oil (i.e. by available prechamber concepts or with direct injection prototypes from Elsbett). Esterified rape seed oil as diesel fuel is now produced in Austria (about 30 000 t/a). The "Elsbett" engine did not enter a commercial stage; the author sees some unanswered questions regarding first costs, long term durability, non existing fuel standards, difficult fuel handling at low temperatures and incomplete assessments of exhaust gas emissions.

3.3 Transmissions

3.3.1 Introduction

Most tractor engineers define the "transmission" as the arangement of the gearbox (with master clutch) with rear axle, pto-drive, four-wheel drive gears and -shaft, brakes and some other elements such as drives for hydraulic pumps. This technical volume represents about 25 to 30% of the total tractor cost. That is considerably more than for any other tractor component (about 50% above engine cost) and requires correspondingly high development and tooling investments.

A survey on tractor transmission developments for the period since about 1950 up to 1985 is included in a tractor book (Renius 1987). Updated state-of-the-art reports have been presented by Renius and Pfab (1990), Renius (1991, 1992b) and Tinker (1993). New fundamentals on overall transmission efficiency have been published by Reiter (1990). Quality-cost-relations for tractor transmissions can be improved substantially by calculations and tests based on load spectra (Renius 1979b).

Incited by the development and availability of hydraulic fluids on vegetable oil basis, similar investigations have been started for transmission oils. This question is important for common circuits of the transmission with the hydraulic system. Remaining problems are seen in the compatibility with wet clutches, brakes and synchronizers.

3.3.2 Stepped ratio transmissions

The most important current tendency can be seen in a change from synchronized to power shifted basic speeds and the introduction of reversers, both in the popular power range from about 60 to 90 kW. Full power shift transmissions have first become popular in North America, for larger tractors, mainly by J. Deere (since 1963), Case-IH (1987) and Ford (1989).Their importance in Europe can be depicted as increasing in the recent years.

The first example for the new trend in the mid power class was the transmission for the Case-IH tractor series "Maxxum" in 1989 offering four power shifted speeds in four synchronized ranges, three of them reversible by power shift. In 1991, Ford followed with the "ElectroShift" in the newly designed "Series 40", also working with four power shifted basic speeds, using however a synchronized reverser. If the customer doesn't need the "high sophisticated" version, he can also order a low cost transmission with only synchronized shift. This philosophy of a wide span of functions seems to be adequate to the large variety of practical needs and has also been realized by J. Deere with the new tractor series "6000" and "7000". The transmission of the "6000" offers, for example, versions from 12/4 ("SynchroPlus" with 12 speeds forward and 4 reverse) to 26/28 ("PowrQuad") at considerably differing prices.

As an example, **Fig.6** shows the concept of the PowrQuad. The diesel engine directly drives the planetary package for the four power shifted basic speeds, followed by the master clutch, the power shifted reverser and the range selection arrangement. Creeper speeds are marked as a specific option. The pto offers not only the international two standard speeds (540 & 1000 rev/min) but also an economic 540 rev/min-drive at reduced engine speed for fuel saving and noise reduction. This principle, which had been introduced in 1980 by Fendt, became very popular in Europe. Electrohydraulic shifts are used by J. Deere (and other companies too) for the pto clutch, the four wheel drive clutch and the differential lock in the rear axle (for some tractors also in the front axle).

3.3.3 Infinitely variable transmissions

Systematic analysis has been resumed since about 1985 by research institutes and also by development in companies. It was stated by the author in previous publications (for example Renius 1987), that conventional hydrostatic drives have no chances for standard tractors of the typical European size, mainly because of their energy losses. Efficiency for a hydrostatic unit consisting of available axial piston pump and motor figure only about 80% in the best point under full load. The tractor however requires best values for the unit above 90% in order to achieve adequate efficiencies above 80% for the complete drive line from gearbox input to axle output. It seems, that there are at present only two concepts for tractor transmissions being able to offer such an efficiency level:

- Infinitely variable chain drives
- Hydrostatic power split transmissions.

The variable chain drive principle, now available in a compact cost effective design, has been applied in the Munich Research Tractor (presented 1988) and is shown in **Fig. 7**. A second tractor prototype with similar, but larger chain drive has been developed in a German cooperation of Schlüter, P.I.V. and Hurth increasing rated engine power up to about 70 kW.

A new hydrostatic power split transmission has been developed by the German company Claas for big tractors and other vehicles using the so called "Jarchow" configuration with nine infinitely power shifted ranges. The concept was described by Jarchow (1989) as well as by Renius and Pfab (1990) and could enter a commercial prototype stage.

3.4 Human engineering

Most European tractors use a close cab for noise reduction and protection from the weather (recently also from chemicals). These cabs emerged in Europe in the seventies with OECD noise levels around 85 dB(A) (at the drivers ear under full load). Meanwhile it was possible to achieve best values of 72 dB(A), while progress in riding comfort is rather less. There are of course excellent seats with air suspension and automatic adjustments, but they allow only limited further reductions of the natural frequency of the driver-seat system. Unfortunately the limited damping performance of tractor tyres decreases with tractor speed and is also lower for radial than for conventional tyres as reported by Kutzbach and Schrogl (1987) as well as by Kising and Göhlich (1988).

Regarding the cab position, a tendency of continuous forwarding can be observed with improvements in the following aspects:

- riding comfort
- access from the side
- front visibility.
- balanced rear mounted implements
- benefits of front axle suspensions (if applied)

Major progress in riding comfort is possible by axle or cab suspensions using springs and dampers, as stated in many publications (Göhlich 1991). An important milestone can be seen in the suspended cab presented in 1987 by Renault for large tractors. In 1989, Bosch and Fendt introduced a new active tractor-implement damping system, based on research of Ulrich and Göhlich (1983) and innovative developments of Hesse (1991). This is now becoming popular because of very low extra first cost, while front axle and cab suspensions require much higher extra costs and will probably be restricted to become an option for large tractors.

Front visibility could be improved not only by the cab position but also by flat engine bonnets, as shown in **Fig. 8**. Many companies introduced this principle as an option, following recommendations presented with the "Munich Research Tractor" in 1988.

"Tractors are involved in a high proportion of fatal and permanent injuries" (Murphy 1992, based on statistics for the United States). Human engineering has therefore also to improve tractor safety in order to curb human suffering and limit economic losses. Considerable progress could be achieved by the former introduction of safety frames as compulsory equipment, now integrated into the cab. **Fig. 9** demonstrates that the number of tractor overturn fatalities could be reduced in Germany by about 90%, which can be regarded as an outstanding progress rate. Further safety improvements now concentrate on mounting and dismounting the tractor (Latif and Christianson 1988) or coupling implements (Graef, Speckmann and Vellguth 1992).

3.5 Hydraulics and implement control

Front hitch and front pto became popular in Europe for standard tractors and are now offered as an "integrated option" for most tractor models. However, the tractor rear clearly remained the main interface, number of functions is even higher than ever before, **Fig. 10**. International standards of ISO have been established or are under development for all connecting elements. The status of a digital serial communication standard (BUS) for tractor-implement systems was described by Stone and Zachos (1992), a general review of electronics for tractors is available by the book of Auernhammer (1991).

The electronic three point hitch control (rear), which had been introduced for the first time in 1978 by Hesse (BOSCH, Germany), became popular after the introduction of the BOSCH force sensing pin in 1982 enabling a cost reduction of the former very complicated spring systems and improving flexibility for the design of the tractor rear. At the same time, the top link draft sensing was loosing importance in favour of lower link sensing concepts. The most recent trend in electronic three-point hitch control is represented by the introduction of digital data processing instead of the previous analogue system (Hesse, 1991). Another very important trend concerns fundamental changes of the supply system for hydrostatic power. Gear pumps have been used over decades for tractors being very economic in first cost and reliability, but not being able to adjust the flow rate to actual needs of tractor and implement.

John Deere was in 1960 the first manufacturer to use variable displacement pumps for mass production of tractors working in a "constant pressure" hydraulic system. Allis Chalmers presented the more sophisticated "load-sensing" system in 1973 for the first time for tractors (Khatti, 1973), also with variable displacement pump. The main objective was energy saving, which could be confirmed later by Harms (1980), Jarboe (1983) and others. The working principle shown in **Fig. 11**, adopted from Matthies (1991). A variable displacement pump keeps the pressure drop of the service valve Δp constant, independent of valve set and pressure load level. The provided flow rate of the valve is therefore close to a linear function of the valve setting, offering interesting prospects for electro-hydraulic speed control of hydrostatic motors and actuators. When the valve is closed, the pump moves to a "near zero displacement" position with a low stand-by pressure in order to minimize power consumption. Practical energy saving potential depends highly on load and flow histories, as investigated by Garbers (1986). Circuit strategies for simultaneous operation of more than one actuator or motor have been demonstrated for example by Harms (1980) and Esders (1992). Case-IH introduced the load-sensing system with the "Magnum" in 1987, Ford with the "Series 40" in 1991 and J. Deere with the series "6000" and "7000" in late 1992. Further companies will follow.

Other research and development has been started to investigate use of vegetable oils as a biodegradable basis for hydraulic fluids to solve environmental problems caused by oil leakage. First products are on the market with encouraging field test results. The use for common oil circuits with the transmission seems however not to be practicable yet as outlined in the chapter 3.3.1.

Conclusions

The agricultural tractor remains worldwide the key machine of farm mechanization changing its role in highly developed countries from a unified mass product to customer-specified high-power units in reduced numbers. Main consequences for industry concern cooperation, concentration, flexibility and improved quality.

The standard tractor with different tyre diameters and Ackermann-steering will remain the leading concept, whereby the "Ford-rule" of using engine and transmission as a block chassis will likely loose importance gradually in favour of frame concepts. The four-wheel drive will remain popular in specific regions such as Europe and Japan. Many efforts concentrate on its further improvement also considering front axle suspensions. A top speed of 40 km/h will settle within the next years in Europe, although brakes on both axles are necessary. Turbo charging and high injection pressures are going to become standard for diesel engines above a certain power level (also with intercoolers) in order to meet expected emission regulations and to reduce tractor weights.

Transmissions with three or four power shifted basic speeds for the medium power classes and often full power shift for the upper classes will become typical in Europe within the near future. Infinitely variable transmissions with considerably improved efficiencies are under research. Electronics will be introduced for power train management.

Riding comfort problems will be solved by tractor-implement damping systems, front axle suspensions and perhaps also by further cab suspensions. Safety improvements now concern tractor access and implement coupling, while overturn fatalities could be reduced drastically in Europe due to compulsory safety frames.

Hydraulics will continue its fundamental move towards "load-sensing" systems saving energy and enabling improved electro hydraulic tractor and implement control. First vegetable oils for hydraulics are on the market, but they are not yet suitable for transmissions.

Electronics play an increasing role for control, information and automation of the tractor–implement working process with a trend from analog to digital data processing.

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Table 1: West European tractor business (by units).

Year	Production	Registrations
1983	368 000	276 000
1987	278 000	218 000
1988	293 000	225 000
1989	298 000	219 000
1990	291 000	198 000
1991	231 000	169 000

Table 2: Typical structure of a European tractor line (1993, model).

Size group	1	2	2a	3
Rated engine power, kW	25 – 50	50 – 75	75 – 90	90 – 150
Rated engine speed, rev/min	2000 to 2500			
Diesel-engine (Displacement per cylinder is about 1 liter)	3 cylinder (Turbo ch.) –	4 cylinder (Turbo ch.) (Intercooler)	6 cylinder – –	6 cylinder (Turbo ch.) (Intercooler)
Volume of functions	moderate	large (options!)		large
Comfort level	moderate	high		very high
Market volume	moderate	high		moderate

Table 3: Typical specifications (model) of a popular European tractor with 68 kW rated engine power (which was the average power of sales in Germany 1992).

Dimensions	Shipping weight 4.0 t, payload 3 t, wheelbase 2.4 m, height 2.6 m
Chassis	Four-wheel drive, tyres 16.9R24/18.4-34, power steering, max. 50–55°
Engine	Turbo charged 4-cyl., 4 l, 68 kW at 2300 min^{-1}, min. 205 g/kWh
Gear box, pto's	24 speeds forward 1.5–40 km/h, reverser (1.5–20 km/h), all shifts synchr., 4 speeds opt. power shifted, rear pto 540/750/1000, front 1000 rpm opt.
Working place	Closed safety cab (75 dBA/OECD), doors on both sides, right hand panel, air suspended main seat, easy designed 2nd seat. Options: On-board computer, radar sensor, air conditioning, adjust. steering wheel
Hydraulic power	Two gear pumps (35+40 l/min, 175 bar) or opt. variable displacement axial piston pump (0–80 l/min, 200 bar, load sensing). Two (opt. 4) remote control valves
Three-point hitches	Rear hitch with 45 kN max. force at lower links, digital control (draft, position, mix, damping). Front hitch opt., quick couplers front & rear
Control aids	Automatic shift functions for diff. locks (front, rear), for four-wheel drive, for rear hitch; semi-automatic pto shift (button), multi function levers

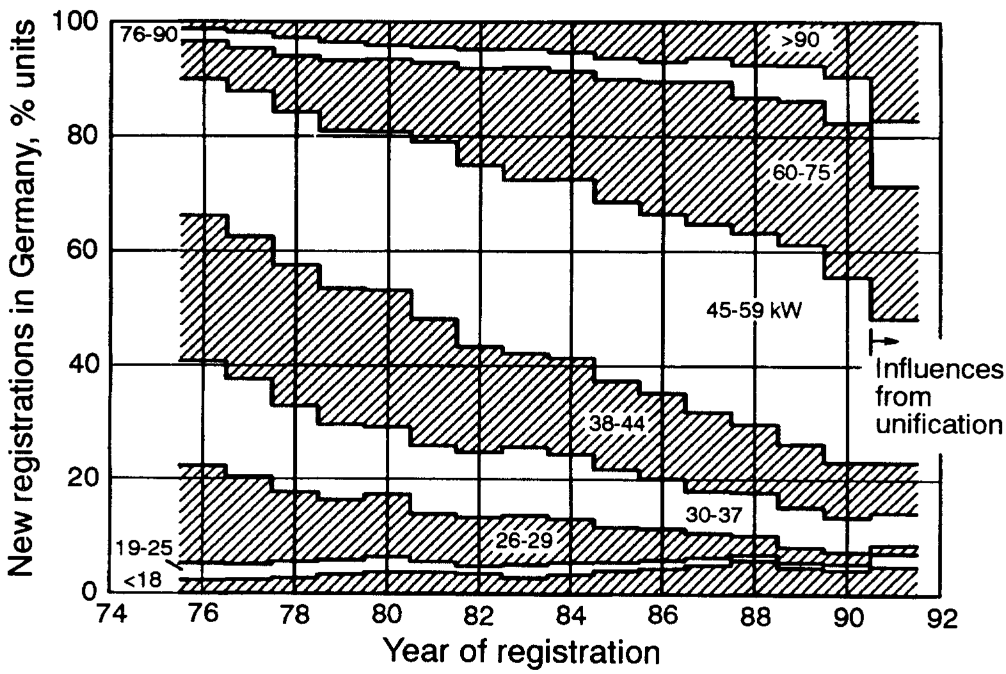


Fig. 1: Tractor power classes (rated engine kW) for newly registered tractors (up to 1990 for West Germany, from 1991 for the unified Germany).

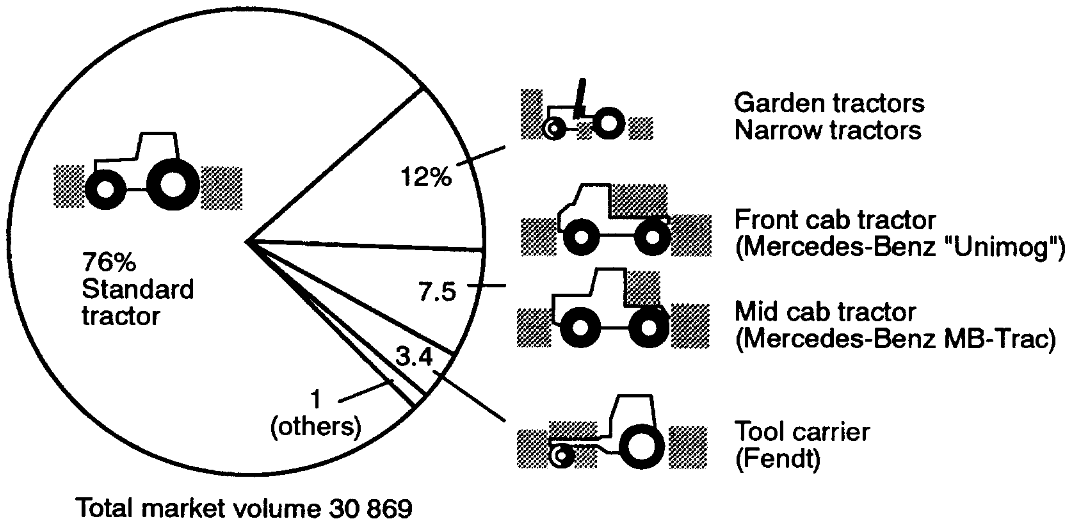


Fig. 2: Tractor market in Germany by concepts 1992 (data courtesy X. Fendt & Co.).

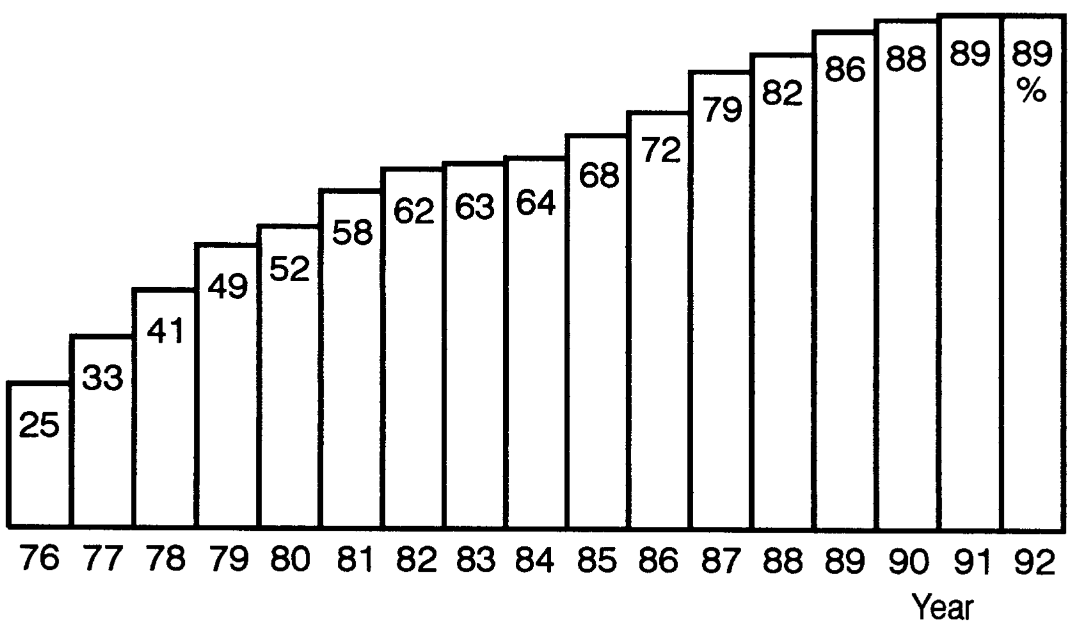


Fig. 3: Four-wheel drive market shares of newly registered tractors in West Germany (data courtesy X. Fendt & Co.).

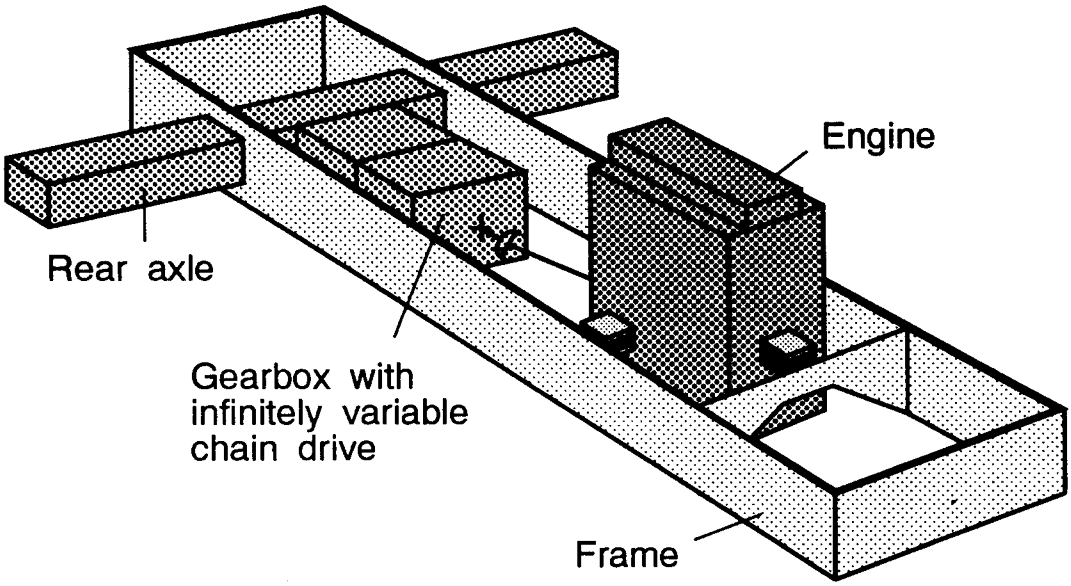


Fig. 4: Frame and power train of the "Munich Research Tractor" (1988).

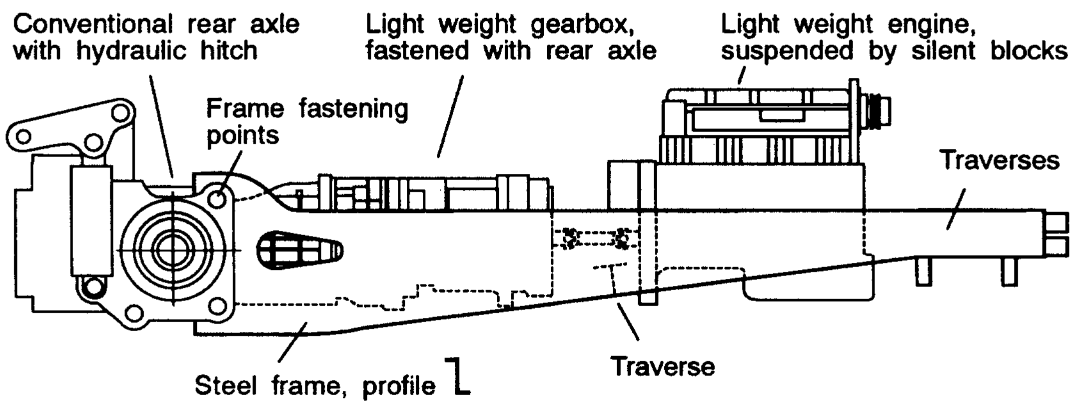


Fig. 5: Frame and power train of the new J.Deere tractor series "6000" (Sept. 1992).

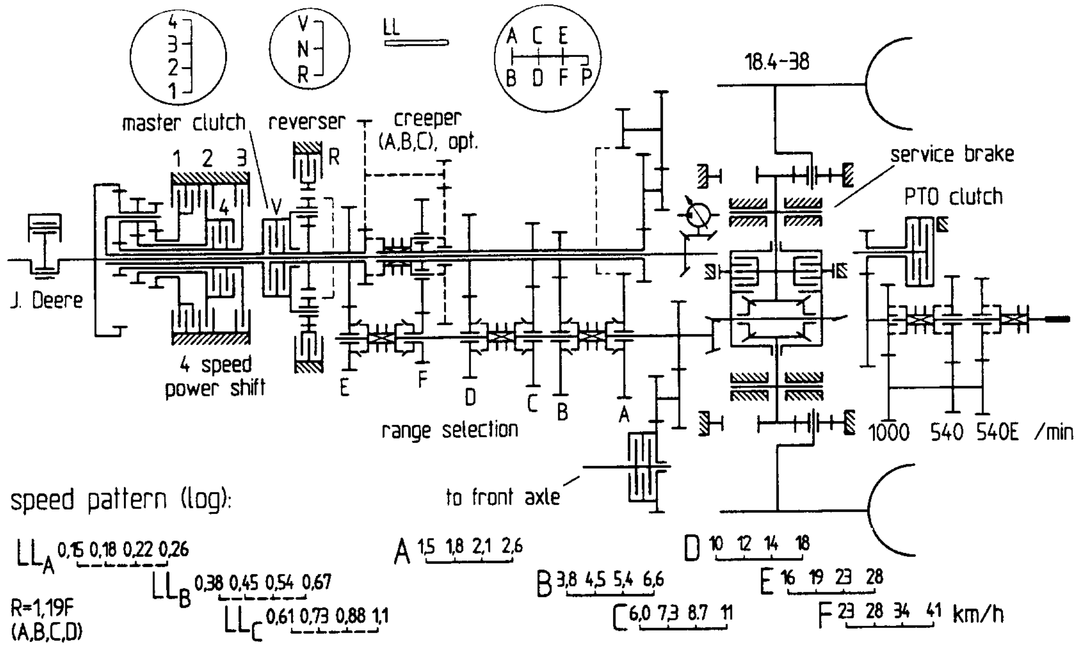


Fig. 6: 36/28-transmission J.Deere "PowrQuad" with power shift of four basic speeds, synchronized reverser and synchronized ranges (except optional creeper). Transmission presented with tractor series "6000" and "7000" (1992), details relate to "6000" series.

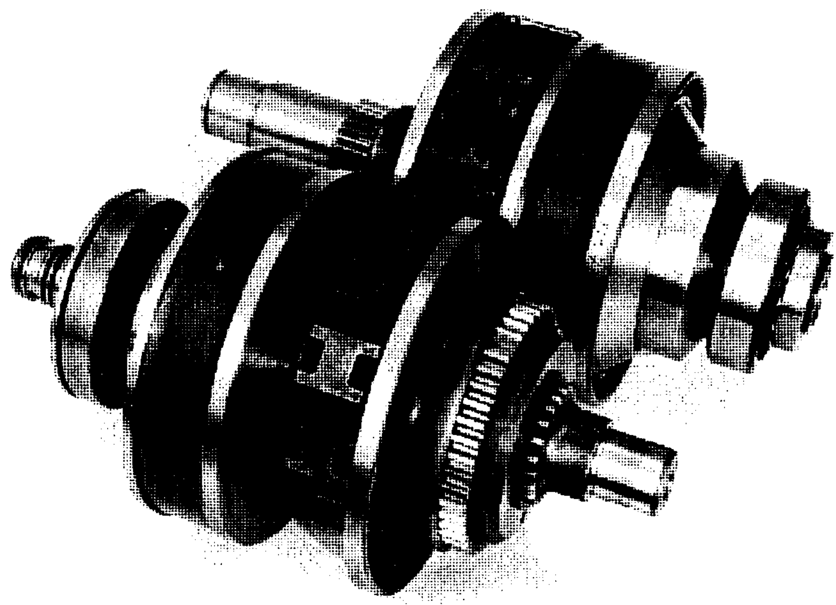


Fig. 7: Infinitely variable chain variator unit of the "Munich Research Tractor"(cooperation by P.I.V. Antrieb Werner Reimers, Bad Homburg and Technical University of Munich).

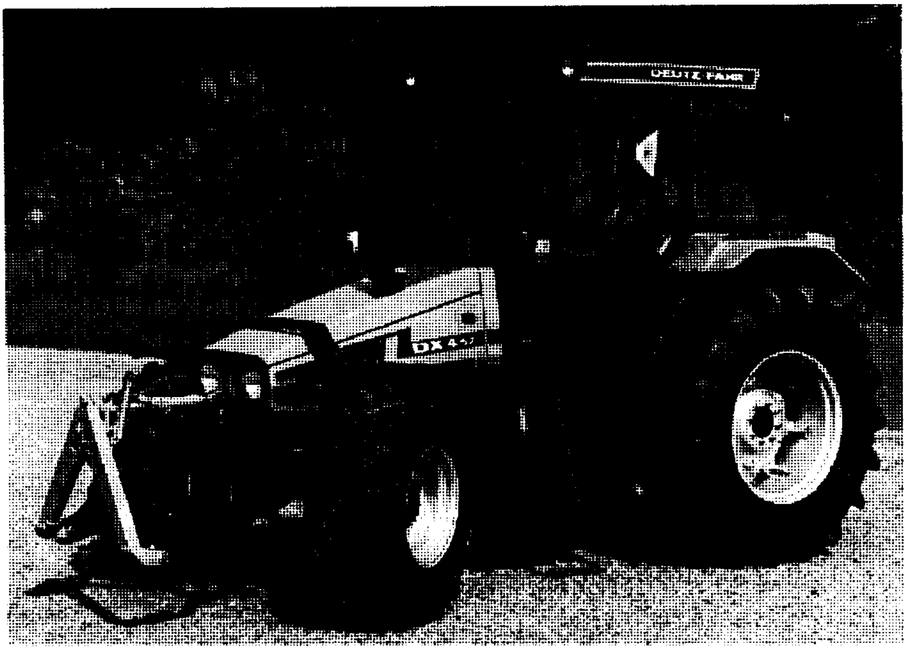


Fig. 8: Deutz tractor series "AgroXtra" (1991) with flat engine bonnet for improved front visibility.

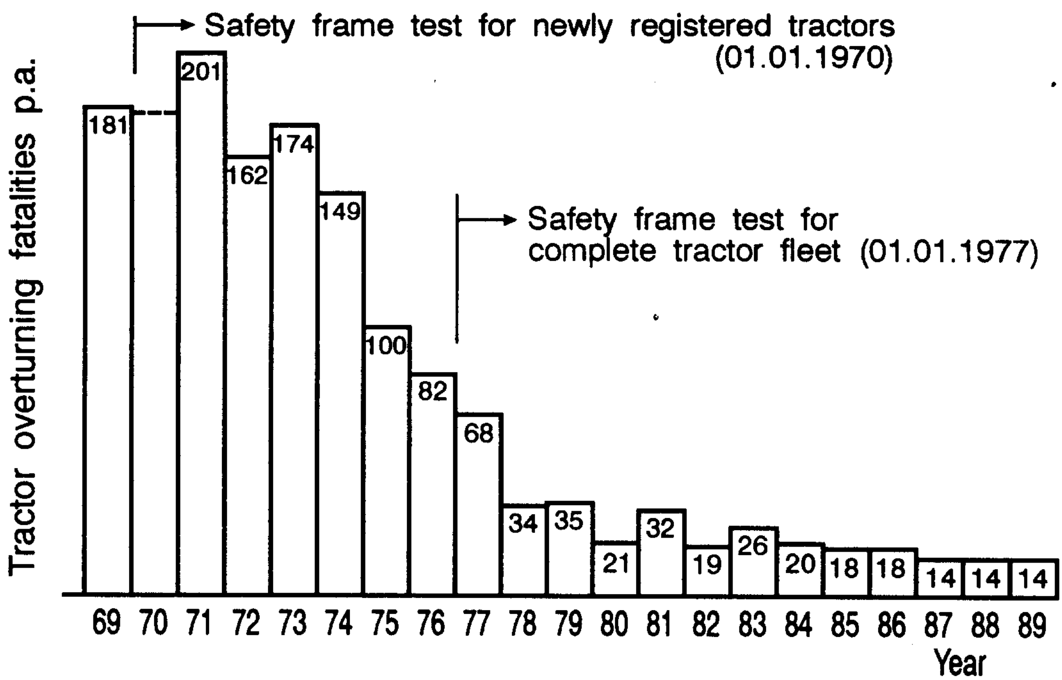
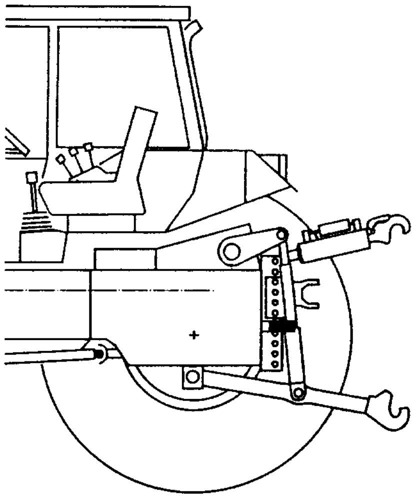


Fig. 9: Tractor overturn fatalities for West Germany (courtesy M. Brübach, Bundesverband der Landwirtschaftlichen Berufsgenossenschaften, Kassel / Germany).



- ■ 3-point hitch: Autom. load-, position-, mixed-control
- □ 3-point hitch: Quick-coupler (top link, lower links)
- □ 3-point hitch: Automatic slip-control
- □ 3-point hitch: Automatic dampening of vibrations
- □ 3-point hitch: Activation by implement sensor
- □ 3-point hitch: Remote control from outside the cab
- ■ PTO with 540 and 1000/min
- □ PTO: Additional economy speeds
- □ PTO: Remote control from outside the cab
- ■ Trailer hitch (manual or automatic)
- ■ Swinging drawbar
- ■ Low position hook hitch, movable up – down
- ■ Low position hook hitch, rigid (»piton fix«)
- ■ Hydraulic couplings
- ■ Couplings for trailer lights & brake operation
- □ Coupling for 12 V power supply
- □ Electronic interface coupling

□ recently introduced

Fig. 10: Function increase at the rear interface of West European standard tractors.

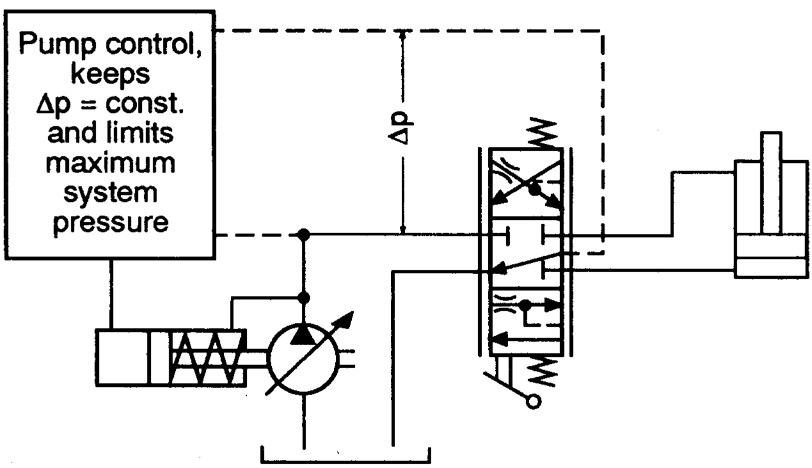


Fig. 11: Principle of "load sensing" system for hydrostatic power supply of tractors with a variable displacement pump (diagram adopted from Matthies). Symbols ISO 1219.