Henry George (Harry) Ferguson (1884–1960)

Gordon R. Pennock

Abstract This article reviews the life and significant contributions of Henry George (Harry) Ferguson, the pioneer of a system of farm mechanization which helped to revolutionize agriculture. Ferguson, see Fig. 1, was the inventor of the tractor that bears his name and which led to a partnership with Henry Ford and eventually to the Massey-Ferguson tractor. Ferguson was a philanthropist with a single-focus mission, the aim of which was agricultural production. During his lifetime it was this production which controlled the cost of living. As an employee of the Irish Department of Agriculture, during World War I, he supervised the operation and maintenance of the small number of tractors that were then in use. He came to the realization that efficient agriculture based on mechanization was the only solution to the problems of the world's food supply. He devoted his time and energy to the development of equipment which he believed would reduce the cost of food production and the cost of living. His passion to mechanize farming to the highest degree, occupied most of his working life. He was a man with a never-let-up personal drive and had a love for building and tinkering with machines. Ferguson received some 100 patents on improvements in carburetors for internal combustion engines, improvements relating to tractor plows, and the means for coupling agricultural implements to tractors. He was a brilliant engineer who brought about a major change in tractor design with his revolutionary linkage, the three point hitch, that allowed both tractor and implement to work as an integrated unit. Today, virtually all tractors are based in some manner on the unique ideas of Ferguson.

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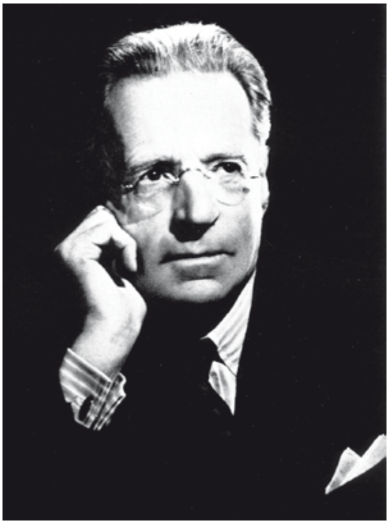


Fig. 1 Henry George (Harry) Ferguson (*c*.1930)

Biographical Notes

James Ferguson married Mary (Minnie) Bell on July 1, 1879, and over the next 24 years, 11 children were born into the family; namely, Joseph Bell Ferguson, James Patterson, Margaret Elizabeth, Henry George, Mary Agnes, Norman Priestly, William Edwin Persis, Sarah Ludley Agnew, John Victor Stanley, Edgar McKnight, and Hugh Fisher (www.proni.gov.uk). The children were born on their father's farm at Growell, in the parish of Dromore, 5 miles from Hillsborough, in County Down. Growell, a townland of scattered farmsteads and cottages, is some 15 miles south of the city of Belfast, the capitol of Northern Ireland. The Ferguson family were members of the Brethren, or Plymouth Brethren, and attended the Growell Gospel Hall. So Henry George, or Harry as he was always called, grew up under the teachings of the Holy Bible. However, he was to turn his back on this Christian influence and later in life he would acknowledge that he was, in fact, an agnostic.

It is interesting to note that Ferguson was born just a few months before Gottlieb Daimler received a patent for his motor-cycle and Karl Benz received a patent for his motor-car (Wymer 1961). By the time Harry was 1 year old, the Daimler motor-cycle and the Benz motor-car were the only petrol driven vehicles on the roads throughout Europe. Ferguson left school at the age of 15 and began working full-time with his father on the farm. His light build, however, proved most unsuitable for the heavy farm labor. In truth, he had no interest in the work. By the age of 17, he was preparing to immigrate to Canada. By most accounts he had the necessary paper work in his possession when the oldest brother Joe offered him the opportunity to serve an apprenticeship in his new business (Fraser 1972, 1973). Joe also had no interest in farm work and had started an apprenticeship, at the age of 15, as a maintenance mechanic with the firm of Combe Barbour, general engineers, making linen machines and other factory machines. Then in 1901, Joe joined with two other ex-apprentices from Combe Barbour, Stewart Hamilton and James Alexander McKee, to form the Stewart Partnership on the Shankill Road in North Belfast. This started as a small engineering business but soon concentrated on automobile and motorcycle repairs and, in fact, this was one of the first garages in the city of Belfast. A short time later, Joe opened his own garage on Little Donegall Street in Belfast and called his business, J.B. Ferguson and Company, Automobile Engineers. Later in life he was to own a car dealership in New York.

Belfast (from the Gallic, or Irish language – *Béal Feirste* – meaning sandy ford at river mouth) was originally a town in County Antrim (http://en.wikipedia.org./wiki/belfast). The County Borough of Belfast was created when it was granted city status in 1888 by Queen Victoria. The population within the city limits at that time, according to the 1881 census, was 208,122 (www.nirsa.gov.uk). The city is situated on the eastern coast and is flanked to the northwest by a series of hills, including the Cavehill which is thought to be the inspiration for Gulliver's Travels, a novel by the Irish writer Jonathan Swift. Belfast is a port city, located at the western end of Belfast Lough at the mouth of the River Lagan, making it an ideal location for the shipbuilding industry that once made it famous. When the Titanic was built there in 1912, Harland and Wolff was the largest shipyard in the world. This shipyard with its giant cranes, which could be seen from most parts of the city, is renowned for building many famous ships. The Olympic-class ocean liners which were a trio of the largest and most luxurious ocean liners of their time (namely the RMS Titanic, RMS Olympic and HMHS Britannic) were built there between 1908 and 1914. During and immediately after the Second World War, Belfast was an industrial city known around the world not only for the building of large ships, but for aircraft manufacture, the linen industry, and rope manufacturing. Not far from the shipyard is the aircraft factory, Short Brothers and Harland, which is renowned for the building of freight, and small passenger, aircraft. In the early 1960s, the factory would gain notoriety for its pioneering work with a vertical take-off and landing (VTOL) research aircraft known as the SC1. The Rolls-Royce Flying Bedstead proved the vertical lift capabilities of the RB108 engines, but only flew in England. Belfast is also the birthplace of many famous engineers and mathematicians, including, William Thomson, perhaps better known as Lord Kelvin (1824–1907), Osborne Reynolds (1842–1912), John Greenlees Semple (1904–1985), and John Stewart Bell (1928–1990).

So it was in this city, in the year 1901, that Harry Ferguson joined his brother as an apprentice mechanic in the car and cycle repair shop. They were very successful in both motor-cycle and car racing and established what was described by many as the best garage business of its kind within the city limits. Harry showed he had a natural gift for mechanics and engineering. In 1903, he built a motor-cycle to his own design and won a hill test to determine how its performance would compare with factory production motor-cycles. He also won several road races and trials. Then in 1907, he built and raced his own car. For most of his life, Harry promoted motor-cycle and car racing. His efforts led to the Stormont Road Races Act of 1932, which made possible the first Ulster Grand Prix on the roads of Northern Ireland. He also lobbied the Royal Automobile Club (RAC) to organize the famous Tourist Trophy (TT) motor cycle races (1928–1936). In later life, Harry would apply himself to the design of four-wheel drive cars. He designed the Ferguson Formula car which could transmit traction and braking torque equally to all four wheels. This resulted in the four-wheel drive, using controlled differentials to govern the speeds of the individual wheels. The differential had a limited range of motion only, the front wheels could travel up to 15% faster than the rear wheels (which is a condition required when turning a circle at maximum lock). The rear wheels could turn 5% faster than the front wheels, which was the margin to allow for deflation of a rear tyre. If there was a tendency for greater speed variations than these values, then the differential would lock and all four wheels would be driven at the same speed. The master differential allowed the use of the Maxaret anti-lock brake system that was developed by Dunlop, initially for aircraft wheels. Ferguson developed the first Formula 1 racing car with all wheel drive, the car was the Ferguson P99 (http://en.wikipedia.org./wiki/ferguson), the system included viscous coupling and the anti-lock braking system. The British race car driver Stirling Moss raced a car of this design in the 1960 and 1961 Formula 1 World Championships. Moss, one of the most successful Formula 1 racing car drivers until he was forced to retire in 1962, won the Gold Cup at Oulton Park with the P99. This, of course, was before four-wheel drive cars were excluded from the racing circuit. The P99 also won the British Hill Climb Championship on two occasions. The system, designed by Ferguson was later used in the Jensen FF car. This car had a four-wheel drive system with unequal front/rear torque splitting, a self-locking center differential, and the Maxaret anti-lock brake unit.

By the age of 25, Ferguson had designed and flown a monoplane (http://www.uftm.org.uk). Apparently his initial interest in aviation was galvanized by the excitement generated over Bleriot's crossing of the English Channel in July 1909. He attended the flying meetings at Rheims in August of that year and the Paris Air Exhibition in September. He started to build his first aeroplane immediately upon his return. Although Harry's main expertise was in the building and tuning of engines, he had studied all the aircraft on display in France in great detail, and this enabled him to mastermind the construction of the aircraft on the premises of J. B. Ferguson and Company Ltd., while his brother Joe was in America on motor-related business. Ferguson was the first Briton to build and successfully fly a powered aeroplane in Ireland, this was only 6 years after the pioneering flight of the Wright brothers. While early attempts to get airborne were unsuccessful, he did manage his first flight of this small monoplane on December 31, 1909, at Hillsborough. Ferguson faced the aeroplane into the wind, and with the power of an eight-cylinder engine, raised the aeroplane into the air to a height of about 12 ft. Apparently the aeroplane traveled a total distance of about 130 yards before Ferguson brought it back to earth for a safe landing. Ferguson also flew the monoplane at Magilligan Strand, County Londonderry. His flight at Dundrum Bay, just north-east of Newcastle, County Down, in August 1910, was officially recognized by the Aeroplane Club. He won a cash prize of £100 offered for a 2 miles flight, although Harry flew closer to 3 miles. A man who claimed to have helped Ferguson construct the monoplane was William John Sands (Flackes 1960) who lived on the Old Hillsborough Road, Lisburn, County Down. Due to his age at that time, however, it appears unlikely that Sands worked on the early version of the Ferguson aeroplane. Two friends, Joseph Martin and John L. Williams, however, were prominent throughout the design, building and flight testing of the aircraft. Joe lived in Dromore, County Down, and worked for J.B. Ferguson. He was an expert in building spoked wheels for motor cars. Sands was about 19 years old when he was employed by Ferguson, after serving an apprenticeship in the maintenance of machinery for the linen industry. He also operated a small car repair business on the Lisburn Road. Sands would end up working for Ferguson for more than 35 years, and their association would cover almost 50 years. They had a friendship which survived some very sharp disagreements. In fact, Sands would testify against Ferguson during the infamous lawsuit filed by Ferguson in January 1948 against the Ford Motor Company. Sands had come to believe that he was the true inventor of the Ferguson System (see the following section) and while Sands was an engineering genius in his own right, he was a designer and not an inventor. In the lawsuit against the Ford Motor Company, Ferguson was seeking damages in excess of $250 million on the grounds that Ford had conspired to destroy the Ferguson business and for alleged infringement of several Ferguson patents. The lawsuit was finally settled out of court some 4 years later, in April 1952, for less than $10 million in damages to Ferguson in payment of royalties on patented devices used by Ford after the break-up with Ferguson. These devices comprised, in large part, the Ferguson System.

Harry opened his own motor repair business in Belfast, in 1911, which he called the May Street Motor Company, Limited. Harry would eventually move the business to Lower Donegall Street East. Joe Martin went with Harry to May Street and John Williams also worked for Harry up to the time of his untimely death in 1940. Two other gentlemen who worked for Ferguson were Hugh Reid, who joined the company as a journeyman draughtsman in 1918, and Joseph Thompson, who started as an apprentice and, for many years, was manager of Harry Ferguson (Motors) Limited in Belfast. Subsequently, Thompson bought the business and it was renamed Thompson-Reid Limited. It is interesting to note that the internal combustion engine which was to play such an integral part in the automobile industry, in general, and tractors, in particular, was invented in 1885, just a few months after Harry was born. In 1913, Ferguson married a local girl called Maureen Watson in a registry office in Newry, County Down. The following year, as a loyalist, he was involved in gun running for the Ulster Volunteer Force. Then when the First World War broke out, the Irish Department of Agriculture offered him a wartime Governmental post. At this time, Harry was the agent for a 20 horse power American tractor, called the Overtime. The department asked Ferguson to supervise the operation and maintenance of the small number of tractors that were in use at that time to increase domestic food production. This could be described as the turning point in the life of Harry Ferguson. It was his introduction to the mechanization of agriculture, and the beginning of his focus on plow design. He came to the conclusion that efficient agriculture based on mechanization was the only solution to the problems of food supply around the world. He put all his energy into the development of equipment which he believed would bring down the cost of food production and the cost of living. William J. Sands was with Ferguson during the campaign to increase tractor usage and food production in Ireland during the First World War. He provided a clue to the origin of Ferguson's obsession with agricultural production in pointing out that Ferguson consulted with Dr. Wibberley of Queen's University, Belfast, who had written a book on farming along factory lines (Flackes 1960).

The Overtime tractor was a very heavy machine (it weighed over 2 tons) and dangerous to operate. Ferguson was of the opinion that only a tractor of his own design would do justice to his new plow. He came to the conclusion that the whole idea of making a tractor as one unit, and the implement as another, was entirely wrong. Ferguson designed and built a plow in 1917 which would increase efficiency in food production. His plow was to be coupled to the tractor by a three point linkage, that is, the three-point hitch (Rae 1980). It is interesting to note that Henry Ford began to work on developing a light, cheap and durable tractor as early as 1907, but did not arrive at a satisfactory design until about 1915. As fate would have it, the first Henry Ford tractor (named the Fordson) went into production in 1917. The plow that Ferguson developed, commonly referred to as the "Belfast plough", was first linked to the Model T Ford but was then designed specifically for the Fordson tractor. The man who translated Ferguson's plow ideas into metal was William John Sands. The new two-furrow implement was presented to the farming public at a demonstration in Coleraine, County Antrim. However, in 1918, the Ferguson plow was not at the level of perfection to which the designer aspired. He patented the duplex hitch in that year. However, patents were typically sacrificed because there was not enough money to keep them alive. Also, in that year of 1918, Harry and Maureen had a daughter Elizabeth (Betty). She was to be their only child. Betty would marry Anthony J. Sheldon, an employee in the Ferguson Company. They would have a daughter Sally (she would marry and become Mrs. Sally Fleming), and a son Jamie. The Ferguson Family Museum is currently operated by Jamie on the Isle of Wight (www.ferguson-museum.co.uk).

By 1920, the British farmer had still not decided that the tractor had come to stay. Ferguson and Sands traveled to the United States to visit Henry Ford and show him their, still from perfect, design. Ford offered Ferguson a position in his organization to develop the plow further but refused to provide him with manufacturing facilities. Preferring to remain independent, Ferguson refused the offer. The story of Ferguson's struggle throughout the 1920s and much of the 1930s is one of never giving up in face of repeated frustrations. Fortunately, he had the support of some fine men during this time, many of whom he had first met while taking technical courses at the Belfast Technological College. These men included Captain John L. Williams, Joseph Thompson, Ernest Hamilton Browne, Trevor Knox, Archibald Greer, John Chambers, and T. MacGregor Greer. In 1921, Ferguson took his plow to the Fordson tractor plant in Cork, Ireland, to carry out further tests with some of the Ford staff. The Fordson, as previously mentioned, was a light tractor with many of the same faults as the other light tractors of that period. However, little came from this interaction and Ferguson continued to focus on the development of his plow. He made an arrangement with the Shunk Company, Bucyrus, Ohio to manufacture the plow (Neufeld 1969). Then the business was shifted to Indiana and the Ferguson-Sherman Corporation of Indiana was formed in the town of Evansville, in the southern part of the state. This company was a sales organization which sold thousands of his hand-lift plows with automatic depth control. Some of the components for the Ferguson plow were manufactured at the near-by Vulcan Plow Company.

List of Main Works

During his life time, Ferguson would compile over 100 patents (http://www.google.com/patents; http://ep.espacenet.com) beginning in 1912, with improvements in and relating to carburetors for internal combustion engines, and continuing up through 1950. Most of the patents after 1915 would relate to improvements in the tractor, the plow and agricultural implements, for example, GB119883: Improvements relating to tractor ploughs; GB122703: Improvements relating to ploughs; CA200513: Plough; FR527705: Perfectionnements aux moyens d'accouplement des instruments aratoires; US1379399: Means for coupling agricultural machinery; CA207827: Plough; US1464130: Means for coupling agricultural implements; CA234363: Means of coupling agricultural implements to tractors; CA233226: Agricultural implement; US1501652: Agricultural implement; US1501651: Agricultural implement; CA236960: Agricultural implement; US1526972: Plow; and US1529425: Plow. However, the patents that would revolutionize farming were the patents for the Ferguson system, or the Ferguson hydraulic draft control system. The system was covered by numerous patents which dated from 1917 to 1939. Many of these patents owed a great deal to various members of the Ferguson team. However, it was Ferguson's vision which directed them towards specific solutions to the engineering problems.

Review of Main Works on Mechanism Design

The master patent, filed by Ferguson in 1925, was GB253566 and incorporated the principal of draft control whereby the depth of a ground-engaging implement is automatically controlled by reference to the effort, or draft, required to pull it. The movement of the linkage could be controlled by an electric, mechanical, or hydraulic device. This patent also covered draft control by means of the transmission torque of the tractor. Taken from this patent is Fig. 2 which is a schematic diagram of a disk harrow coupled to the hydraulic mechanism in conjunction with the draft control for angling the disks automatically.

The frame (46) is attached to the disk gangs by means of ball joints (47) and, at the forward end, is pivotally attached to the rocker (9). The rods (48), connected to the disk gangs and to the bell crank (49), serve to regulate the angle of the disk

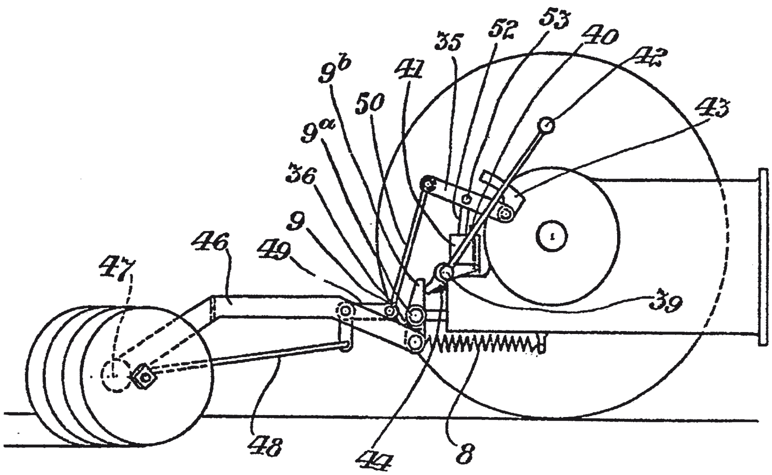


Fig. 2 A schematic diagram of a disk harrow with draft control

gangs. The bell crank is also coupled to the duplex links (35) by means of a rod (50). The duplex links, pivoted on the tractor, are actuated by the piston of the arm cylinder (41) through the piston rod (52) and the crossbar (53). The hand control lever (42) rotates the eccentric shaft (39) on which is mounted a bell crank, which is coupled to the valve (40). A quadrant (43) is provided to retain the hand control lever in any pre-determined position in order to adjust the working depth of the implement. The spring (8) is attached to the rocker (9) and the tractor frame and takes the pull of the implement. Any variation in the pull produces a movement of the rocker which is communicated to the bell crank (pivoted on the eccentric shaft (39) for hand control) which operates a valve (40) and in turn controls the pressure of the oil in the cylinder (41).

The Ferguson system was a system for the mechanization of agricultural operations with the aim and objective of enabling increased production of food and other farm commodities easily, economically and profitably, so that farm products could reach all the people at prices they could afford. The system was a combination of a mechanical linkage and a hydraulic mechanism for controlling the operation of farm implements. The original version of the Ferguson system is shown in Fig. 3 where A denotes the neutral position, B denotes the raised position, and C denotes the lowered position (Morling 1979). The essential features of the system are: (a) integration of the implements with the tractor; (b) hitch geometry to keep the front end of the tractor on the ground (i.e., weight transfer from the implement to the rear wheels of the tractor); (c) traction without excessive tractor weight (i.e., implement penetration without excessive implement weight); (d) continuous automatic control of the implement in the soil; (e) quick and simple attachment and detachment of the implements to and from the tractor; (f) protection of the implement from all normal hazards of operation (such as hitting rocks and other hidden obstructions); and (g) finger-tip and automatic hydraulic control and operation of the tractor and the

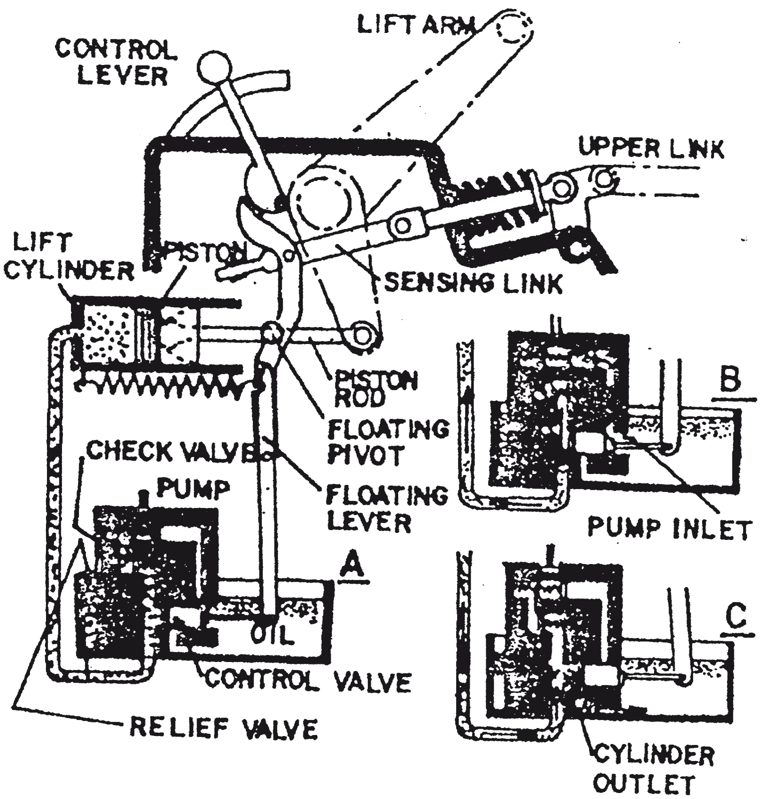


Fig. 3 The original Ferguson draft control hydraulic system

implements. These features were realized with the development of a suitable linkage arrangement between the tractor and the implement, a system of hydraulic controls, and an appropriate tractor. The linkage system, referred to as "the three-point linkage" or "the three-point hitch" was designed with two links at the bottom to pull the implement and one link at the top. It is interesting to note that the original design had two links at the top and one link at the bottom (www.ferguson-museum.co.uk). However, Ferguson quickly realized that this arrangement would not work. The top link served two purposes; namely (a) it served as a rigid restraining brace between the tractor and the implement which prevented the front end of the tractor from rearing backwards off the ground; and (b) as the implement pulled back on the bottom two links (when in the ground), it pushed the top link forward which in turn activated a hydraulic mechanism that tended to exert a lifting force on the implement.

The lifting tendency added weight to the rear wheels and increased traction. It also acted as a counterweight to the front end, shifting front weight to the rear wheels and providing useful traction. Due to the implement reaction forces, the Ferguson tractor could be made lighter and smaller while actually gaining increased stability. This was one of the key features of the Ferguson system. Another important aspect was the method for lifting and lowering the implement and for controlling the depth of the implement in the soil. This was provided by a hydraulic mechanism that was built into the tractor and could be controlled either manually or automatically. Manual control was furnished by a small lever which caused the built-in hydraulic mechanism to lift, lower and adjust the working depth. Automatic control utilized the resistance of the soil as the implement was pulled forward, to activate a control spring through the pushing or compression forces set up in the top link. The control spring in turn governed the hydraulic mechanism, causing it to react automatically, and so govern the working depth of the implement as preset manually. In this manner, an increase in the soil resistance would not stop the progress of the tractor. Rather, it would push the top link forward which, in turn, would cause the hydraulic mechanism to exert a lifting tendency on the implement. This, in turn, would increase the tractive weight on the rear wheels, thereby adding to the pulling ability of the tractor. Furthermore, to the extent that the implement was momentarily lifted out of the soil, allowed the tractor to move forward even under hard-pulling conditions. The implement in the two extreme positions is shown in Fig. 4 (Fraser 1973).

A tractor with the Ferguson system was light, maneuverable, ideally suited for small fields and was applicable to a wide variety of farming implements. The single upper link had improved the draft control but problems remained caused by the continuous pumping of oil under pressure and the tendency to heat and aerate it. In some cases, the problem was so severe that after some 30 min of work, the hydraulic system would airlock. The solution that was proposed by Ferguson was to put the hydraulic control valve on the suction side of the pump. This, in effect, cut off the supply of oil to the pump when no oil under pressure was required to raise the implement. The pump and the control valve had to be submerged in oil. However, Ferguson could foresee no real problems with this arrangement. The control valve, which would be

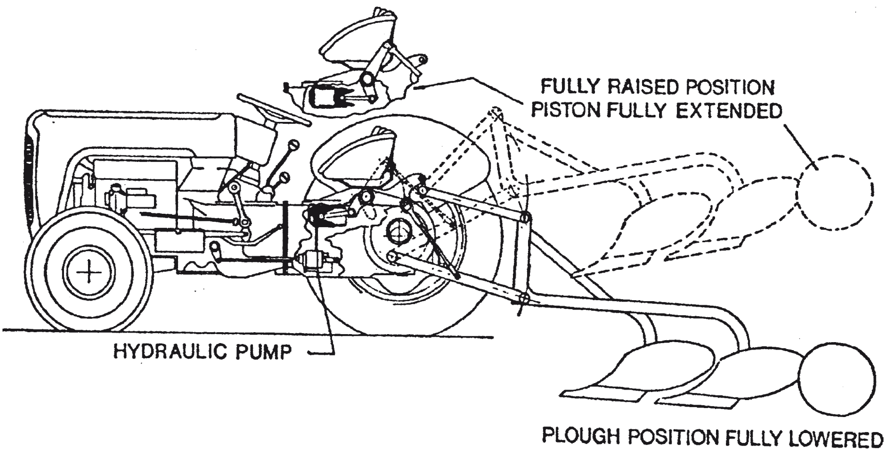


Fig. 4 The implement in the two extreme positions

actuated by the draft forces in the upper link, would be a sleeve running in a housing which was part of the pump. In the housing there would be two ports or openings (an inlet port and an outlet port). When the sleeve valve was centrally located it would block off both ports, thereby retaining the oil in the ram cylinder and holding the lower links at their actual height. If there was an increase in draft as the implement went deeper, the extra compression load in the upper link would slide the valve one way to uncover the inlet port and allow the pump to suck in oil and raise the implement back to the pre-set depth of work. If there was a decrease in draft, the valve would slide the opposite way to uncover the outlet port and allow the oil to escape from the ram cylinder back into the sump, thus lowering the implement.

The automatic mechanism actuated through draft forces in the upper link could, of course, be over-ridden by the lever next to the driver's seat when the driver wanted to raise or lower the implement on the headland or make an adjustment in the working depth. This solution was referred to as suction side control and turned out to be the basic answer to the problem. However, some mild tendency towards bobbing of the implements under certain conditions was to remain for several years. It was finally eliminated by detail changes to the control valve design. Suction side cut-off was the last breakthrough needed to make hydraulic draft control a completely sound and practical proposition. A detailed illustration of the design of the Ferguson system is shown in Fig. 5 (Morling 1979).

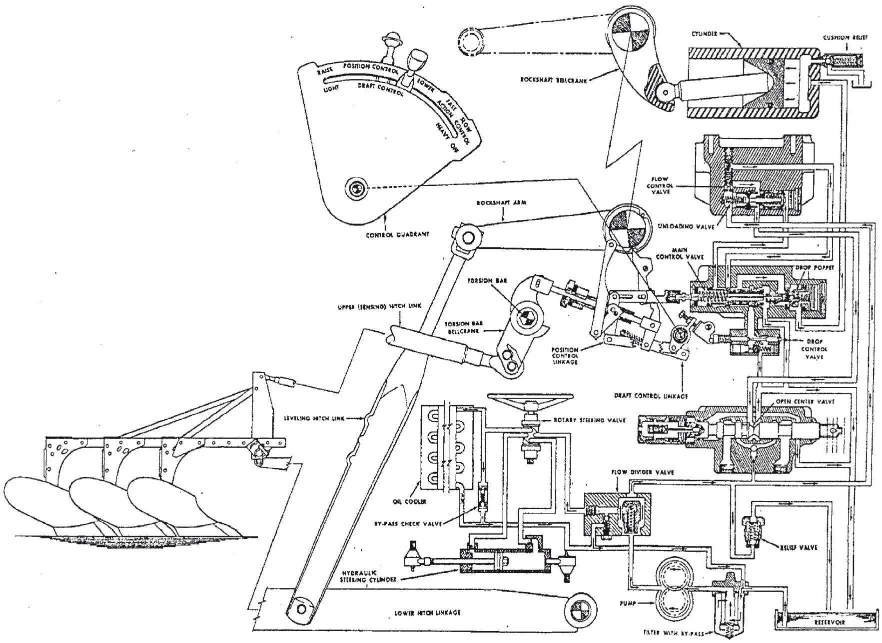


Fig. 5 The design of the Ferguson system

On the Circulation of Works

In 1929, Ferguson claimed to have solved the power farming problem and, in 1930, a demonstration of the tractor system was scheduled for the Northern Ireland government at Andersonstown, on the outskirts of Belfast. However, there were technical details that needed to be resolved and there was the problem of finding the capitol for large-scale production. He asked the Government of Northern Ireland for money to establish his tractor production in Ulster. Lord Craigavon had suggested that financial support would be made available, but nothing happened. The first Ferguson prototype tractor was ready in 1933. The tractor weighed only 16 cwt, compared to the 30 cwt of the lightest tractor then in production. Most of these tractors were built in Belfast and had steel wheels, before tractors had pneumatic tyres. In 1935 after much experiment and engineering development, Ferguson finally claimed to have perfected the Ferguson System. It had taken him almost 16 years to bring the application of hydraulics to mounting implements behind the tractor to what he regarded as a commercially viable platform. This may seem an exceptionally long period of time but it should be remembered that the pumps, control valves, and hydraulic cylinders that he required for the tractor application all had to be designed and developed with no apriori knowledge. The Brown-Ferguson Company was formed about this time and produced the 1354 Model A tractor. The tractors were manufactured in Huddersfield, England, by the David Brown Company. Since the name “Brown” was better known than the name “Ferguson,” the tractors were named the Brown-Ferguson tractors and were introduced in 1936.

Then in 1939, Ferguson entered into a partnership with Henry Ford to sell tractors that incorporated the Ferguson System. This led to the Ford-Ferguson tractor (or the Ford tractor – Ferguson system). More than 300,000 of these tractors were manufactured and sold around the world between 1939 and 1947. It is interesting to note that Ford had never considered entering into any form of a partnership with Ferguson. However, he knew if he was to do business with him, he would have to break his golden rule. They never signed a formal contract, their word was their bond, and they sealed their bargain simply by the shaking of hands. Ford was so impressed with the Ferguson system that he told him “This machine is a work of genius…you have put yourself on a plane with such inventors as the Wright Brothers, Marconi, Edison, and Bell… You will make history!” (Wymer 1961). Soon after World War II, Ferguson and Sir John Black of the Standard Motor Company, Coventry, began manufacturing the Ferguson tractor. The Ferguson TE-20 model (TE referred to Tractor England, there was also a TO model where TO referred to Tractor Overseas) a light-weight tractor was one of the models. It was Ferguson’s most successful design, commonly known as the Little Grey Fergie (or Wee Fergie). Approximately 500,000 of these tractors were manufactured at the Banner Lane plant in Coventry between 1946 and 1954. Hundreds of thousands of successor models were built at this plant for some 50 years until it closed in 2002. The TE-20 was a small but effective design and is a popular collectors’ item for enthusiasts today (Condie 2001).

In 1947, Ford's family (in particular Henry Ford II) reneged on the Ford-Ferguson contract. So in 1948, 9 years after the partnership was formed, Ferguson brought a lawsuit against the Ford Motor Company. The lawsuit was settled in 1952 with Ferguson receiving an estimated 3.3 million pounds sterling (approximately 9.25 million US dollars) in royalties. Ferguson's costs alone were thought to have been in the region of one million pounds sterling. It is important to note that the court refused to renew Ferguson's patent citing its major importance to agriculture and all tractor manufacturers. Surely this was a lasting testament to the engineering ability and ingenuity of Ferguson. In 1953, the Ferguson organization and the Massey-Harris Company, Toronto, amalgamated to form the Massey-Harris-Ferguson Company (later renamed as the Massey-Ferguson Company). The Massey-Harris company was responsible for producing the world's first commercially successful self-propelled combine in 1938. The merger brought together their twin skills in harvesting machinery and tractor design to produce one of the world's most powerful forces in farm equipment. In fact, the merger created a corporation with the second highest sales of farm machinery in the world (Neufeld 1969). However, it was another stormy partnership and in 1954, Ferguson resigned his office in the company. In 1995, the Massey-Ferguson company was purchased by the US-based AGCO Corporation.

Modern Interpretation of the Main Contributions

This section presents a kinematic and dynamic force analysis of the three-point hitch mechanism (Hain 1953, 1955, 1956, 1959, 1973; Hain and Skalweit 1957; Thaer 1956; Phillips 1958; Brock 1954). The method of kinematic coefficients is used to provide geometric insight into the kinematic analysis and the Newton-Euler technique, which also provides physical insight, is used for the dynamic force analysis (Uicker et al. 2003).

(a) Kinematic Analysis. A simple model of the hitch is obtained by assuming that it is symmetrical about the longitudinal axis of the tractor. In this case, each side mechanism (Brock 1954) can be modeled by a planar six-bar mechanism (see Fig. 6). The mechanism is essentially two four-bar linkages coupled by link 3. The input link 2 is actuated by a hydraulic actuator which causes the blade (link 6), in general, and blade point P, in particular, to lift out of and lower into the soil. The blade is attached to the tractor by a lower lift arm (link 4) and an upper link (link 5).

The vectors required for the kinematic analysis are shown in Fig. 6. There are two independent vector loops; namely: the vector loop for links 1, 2, 3 and 4; and the vector loop for links 1, 4, 5 and 6. The first vector loop equation can be written as

$$\overset{\surd I}{\bar{R}_2} + \overset{\surd ?}{\bar{R}_3} - \overset{\surd ?}{\bar{R}_4} - \overset{\surd \surd}{\bar{R}_1} = 0 \qquad (1)$$

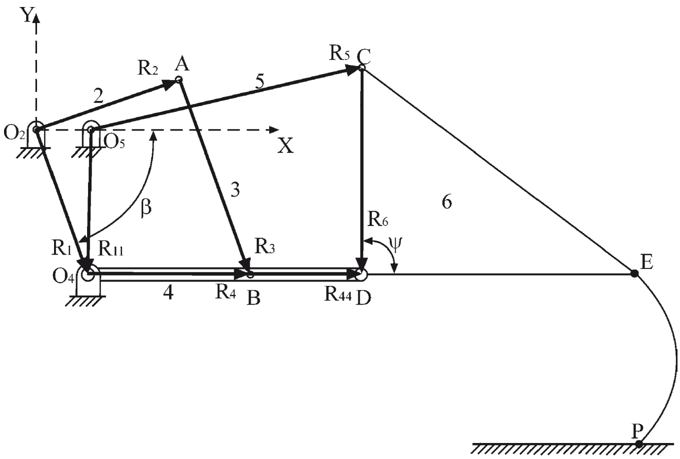


Fig. 6 The three point hitch and the vectors for the mechanism

where the first symbol above each vector indicates the magnitude and the second symbol indicates the direction of the vector with respect to the fixed X-axis. The known quantities are denoted by √, the unknown variables are denoted by ?, and the independent variable (or input θ_2) is denoted by I. For a given position of the input link, the position of links 3 and 4 can be obtained by several techniques, such as trigonometry, or a numerical method, for example, the Newton-Raphson iterative technique (Phillips 1958). Differentiating the X and Y components of Eq. (1) with respect to the input position and writing the resulting equations in matrix form, gives

$$\begin{bmatrix} -R_3 \sin\theta_3 & R_4 \sin\theta_4 \\ R_3 \cos\theta_3 & -R_4 \cos\theta_4 \end{bmatrix} \begin{bmatrix} \theta_3' \\ \theta_4' \end{bmatrix} = \begin{bmatrix} R_2 \sin\theta_2 \\ -R_2 \cos\theta_2 \end{bmatrix} \tag{2}$$

where θ_3' and θ_4' are referred to as the first-order kinematic coefficients of links 3 and 4, respectively (Uicker et al. 2003). Using Cramer's rule, these kinematic coefficients are

$$\theta_3' = \frac{R_2 R_4 \sin(\theta_4 - \theta_2)}{DET} \quad \text{and} \quad \theta_4' = \frac{R_2 R_3 \sin(\theta_3 - \theta_2)}{DET} \tag{3a}$$

where the determinant of the coefficient matrix in Eq. (2) can be written as

$$DET = R_3 R_4 \sin(\theta_3 - \theta_4) \tag{3b}$$

Differentiating the X and Y components of Eq. (1) twice with respect to the input position and writing the resulting equations in matrix form, gives

$$\begin{bmatrix} -R_3 \sin\theta_3 & R_4 \sin\theta_4 \\ R_3 \cos\theta_3 & -R_4 \cos\theta_4 \end{bmatrix} \begin{bmatrix} \theta_3'' \\ \theta_4'' \end{bmatrix} = \begin{bmatrix} R_2 \cos\theta_2 + R_3 \cos\theta_3\, \theta_3'^{2} - R_4 \cos\theta_4\, \theta_4'^{2} \\ R_2 \sin\theta_2 + R_3 \sin\theta_3\, \theta_3'^{2} - R_4 \sin\theta_4\, \theta_4'^{2} \end{bmatrix} \tag{4}$$

where θ_3'' and θ_4'' are referred to as the second-order kinematic coefficients of links 3 and 4, respectively. Using Cramer's rule, these kinematic coefficients can be written as

$$\theta_3'' = \frac{-R_2 R_4 \cos(\theta_2 - \theta_4) - R_3 R_4 \cos(\theta_3 - \theta_4)\theta_3'^{2} + R_4^2 \theta_4'^{2}}{\text{DET}} \tag{5a}$$

and

$$\theta_4'' = \frac{-R_2 R_3 \cos(\theta_2 - \theta_3) - R_3^2 \theta_3'^{2} + R_3 R_4 \cos(\theta_3 - \theta_4)\theta_4'^{2}}{\text{DET}} \tag{5b}$$

where the determinant is given by Eq. (3b).

The second vector loop equation can be written as

$$\vec{R}_5 + \vec{R}_6 - \vec{R}_{44} - \vec{R}_{11} = 0. \tag{6}$$

Differentiating the X and Y components of this equation with respect to the input position gives

$$-R_5 \sin\theta_5\, \theta_5' - R_6 \sin\theta_6\, \theta_6' + R_{44} \sin\theta_4\, \theta_4' = 0 \tag{7a}$$

and

$$R_5 \cos\theta_5\, \theta_5' + R_6 \cos\theta_6\, \theta_6' - R_{44} \cos\theta_4\, \theta_4' = 0. \tag{7b}$$

Then writing these two equations in matrix form gives

$$\begin{bmatrix} -R_5 \sin\theta_5 & -R_6 \sin\theta_6 \\ R_5 \cos\theta_5 & R_6 \cos\theta_6 \end{bmatrix} \begin{bmatrix} \theta_5' \\ \theta_6' \end{bmatrix} = \begin{bmatrix} -R_{44} \sin\theta_4\, \theta_4' \\ R_{44} \cos\theta_4\, \theta_4' \end{bmatrix}. \tag{8}$$

Using Cramer's rule, the first-order kinematic coefficients of links 5 and 6 can be written as

$$\theta_5' = \frac{R_{44} R_6 \sin(\theta_6 - \theta_4)\theta_4'}{\text{DET}} \quad \text{and} \quad \theta_6' = \frac{R_{44} R_5 \sin(\theta_4 - \theta_5)\theta_4'}{\text{DET}} \tag{9}$$

where the determinant of the coefficient matrix in Eq. (8) is

$$\text{DET} = R_5 R_6 \sin(\theta_6 - \theta_5). \tag{10}$$

Differentiating the X and Y components of Eq. (6) twice with respect to the input position and writing the answers in matrix form, gives

$$\begin{bmatrix} -R_5 \sin\theta_5 & -R_6 \sin\theta_6 \\ R_5 \cos\theta_5 & R_6 \cos\theta_6 \end{bmatrix} \begin{bmatrix} \theta_5'' \\ \theta_6'' \end{bmatrix} = \begin{bmatrix} R_5 \cos\theta_5\, \theta_5'^2 + R_6 \cos\theta_6\, \theta_6'^2 - R_{44} \cos\theta_4\, \theta_4'^2 - R_{44} \sin\theta_4\, \theta_4'' \\ R_5 \sin\theta_5\, \theta_5'^2 + R_6 \sin\theta_6\, \theta_6'^2 - R_{44} \sin\theta_4\, \theta_4'^2 + R_{44} \cos\theta_4\, \theta_4'' \end{bmatrix} \quad (11)$$

Using Cramer's rule, the second-order kinematic coefficients of links 5 and 6 can be written as

$$\theta_5'' = \frac{R_6^2\theta_6'^2 + R_5R_6\cos(\theta_5-\theta_6)\theta_5'^2 - R_6R_{44}\cos(\theta_4-\theta_6)\theta_4'^2 - R_6R_{44}\sin(\theta_4-\theta_6)\theta_4''}{DET} \quad (12a)$$

and

$$\theta_6'' = \frac{-R_5^2\theta_5'^2 - R_5R_6\cos(\theta_6-\theta_5)\theta_6'^2 - R_5R_{44}\cos(\theta_4-\theta_5)\theta_4'^2 - R_5R_{44}\sin(\theta_4-\theta_5)\theta_4''}{DET} \quad (12b)$$

where the determinant is given by Eq. (10).

Using the chain rule, the angular velocity and acceleration of link j (= 3, 4, 5 and 6) can be written, respectively, as

$$\omega_j = \theta_j'\,\omega_2 \quad \text{and} \quad \alpha_j = \theta_j''\,\omega_2^2 + \theta_j'\,\alpha_2. \quad (13)$$

Now that the angular velocities and accelerations of the links are known, the kinematics of the blade point P can be investigated. The vector equation for point P, see Fig. 6, can be written as

$$\frac{??}{R_P} = \frac{\surd\surd}{R_1} + \frac{\surd\surd}{R_{44}} + \frac{\surd\surd}{R_{66}} + \frac{\surd\surd}{R_{67}} \quad (14)$$

where $\overline{R}_{66}$ is the vector from pin D to point E and $\overline{R}_{67}$ is the vector from point E to point P. Differentiating the X and Y components of this equation with respect to the input position, the first-order kinematic coefficients of point P are

$$X'_P = -R_{44}\sin\theta_{44}\theta_4' - R_{66}\sin(\theta_6+\psi)\theta'_6 - R_{67}\sin\theta_6\theta_6' \quad (15a)$$

and

$$Y'_P = R_{44}\cos\theta_{44}\theta_4' + R_{66}\cos(\theta_6+\psi)\theta'_6 + R_{67}\cos\theta_6\theta_6'. \quad (15b)$$

Then differentiating these equations with respect to the input position, the second-order kinematic coefficients of point P are

$$\begin{aligned} X''_P = &-R_{44}\cos\theta_{44}\theta_4'^2 - R_{44}\sin\theta_4\theta_4'' - R_{66}\cos(\theta_6+\psi)\theta_6'^2 \\ &- R_{66}\sin(\theta_6+\psi)\theta_6'' - R_{67}\cos\theta_6\theta_6'^2 - R_{67}\sin\theta_6\theta_6'' \end{aligned} \quad (16a)$$

and

$$Y''_P = -R_{44}\sin\theta_{44}\theta_4'^2 + R_{44}\cos\theta_4\theta_4'' - R_{66}\sin(\theta_6+\psi)\theta_6'^2 + R_{66}\cos(\theta_6+\psi)\theta_6'' - R_{67}\sin\theta_6\theta_6'^2 + R_{67}\cos\theta_6\theta_6'' \tag{16b}$$

Finally, the velocity and the acceleration of point P can be written, respectively, as

$$\overline{V}_P = (X'_P\,\hat{i} + Y'_P\,\hat{j})\,\omega_2 \tag{17a}$$

and

$$\overline{A}_P = (X''_P\,\hat{i} + Y''_P\,\hat{j})\,\omega_2^2 + (X'_P\,\hat{i} + Y'_P\,\hat{j})\,\alpha_2. \tag{17b}$$

The geometry of the path of point P can also be expressed in terms of kinematic coefficients. The unit tangent and unit normal vectors to the path of point P are defined, respectively, as

$$\hat{u}^t = \frac{X'_P\,\hat{i} + Y'_P\,\hat{j}}{R'_P} \quad \text{and} \quad \hat{u}^n = \hat{k}\times\hat{u}^t = \frac{-Y'_P\,\hat{i} + X'_P\,\hat{j}}{R'_P}, \tag{18a}$$

where

$$R'_P = \pm\sqrt{\left(X'_P\right)^2 + \left(Y'_P\right)^2}. \tag{18b}$$

The positive sign is chosen if the change in the input position is positive, that is counterclockwise, and the negative sign is chosen if the change in the input position is negative, that is, clockwise.

The radius of the curvature of the path of point P can be written as (Uicker et al. 2003)

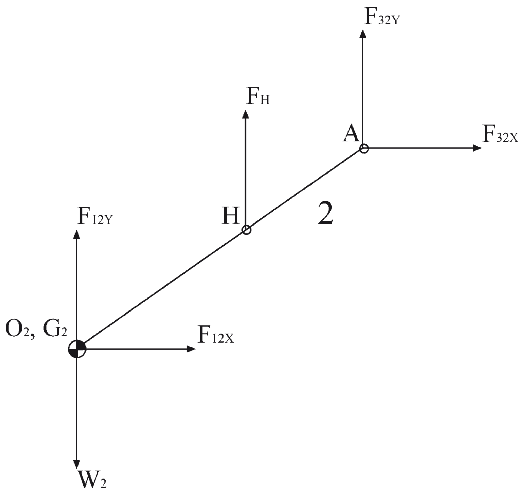
$$\rho_P = \frac{R_P'^{\,3}}{X'_P Y''_P - Y'_P X''_P} \tag{19}$$

where the first and second-order kinematic coefficients of point P are given by Eqs. (15) and (16), respectively. The X and Y coordinates of the center of the curvature of path of point P can be written, respectively, as

$$X_{CC} = X_P - \rho_P\left[\frac{Y'_P}{R'_P}\right] \quad \text{and} \quad Y_{CC} = Y_P + \rho_P\left[\frac{X'_P}{R'_P}\right]. \tag{20}$$

In the design of a three point hitch, the length of link 2 and the range of motion of this link are predefined by the hitch itself (Ambike and Schmiedeler 2007). The length of link 4 (the rocker) is variable, and the designer can select the length of the coupler to produce the desired path, or orientation, for the implement. The desired performance, however, is not defined by traditional motion generation task

Fig. 7 The free body diagram of link 2



requirements (Kinzel et al. 2006). Rather, the typical design goals are to locate the instant center of the coupler (Uicker et al. 2003) (also referred to as the pitch point) in a desirable location, to provide the necessary ground clearance for the implement when it is not in use and to allow for some elevation of the implement without significant change in its orientation.

(b) Dynamic Force Analysis. For convenience, the centers of mass of links 2, 4, and 5 are assumed coincident with the ground pivots O_2, O_4, and O_5, respectively, and the centers of mass of links 3 and 6 are assumed coincident with points B and E, respectively. The actuating force, denoted as $\overline{F}_H$, is provided by a hydraulic actuator which is assumed to act vertically upward at point H, see the free body diagram of link 2 shown in Fig. 7.

From Newton's second law, the sum of the external forces in the X and Y directions can be written, respectively, as

$$F_{12X} + F_{32X} = m_2 A_{G_{2X}} = 0 \tag{21a}$$

and

$$F_{12Y} + F_{32Y} + F_H - W_2 = m_2 A_{G_{2Y}} = 0, \tag{21b}$$

where F_{12X}, F_{12Y}, F_{32X}, and F_{32Y}, are the X and Y components of the internal reaction forces at pins O_2 and A, respectively, and W_2 is the weight of the link. From Euler's equation, the sum of the external moments about the mass center of link 2 can be written as

$$R_{22} \cos\theta_2 F_H + (R_2 \cos\theta_2 F_{32Y} - R_2 \sin\theta_2 F_{32X}) = 0. \tag{22}$$

The free body diagram of link 3 is shown in Fig. 8.

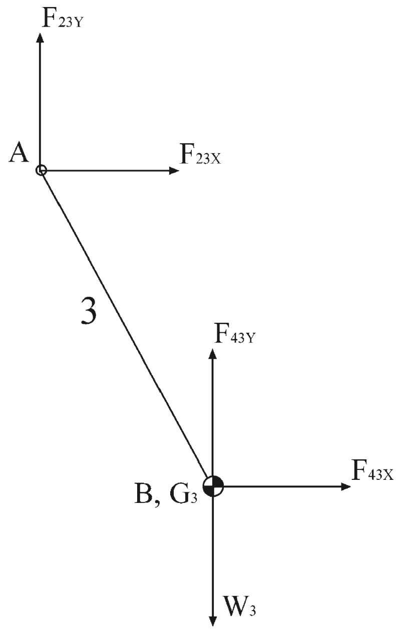


Fig. 8 The free body diagram of link 3

The sum of the external forces in the X and Y directions can be written, respectively, as

$$F_{23X} + F_{43X} = m_3 A_{G_{3X}} \tag{23a}$$

and

$$F_{23Y} + F_{43Y} - W_3 = m_3 A_{G_{3Y}}. \tag{23b}$$

The sum of the external moments about point A can be written as

$$(R_3 \cos\theta_3 F_{43Y} - R_3 \sin\theta_3 F_{43X}) - R_3 \cos\theta_3\, W_3 = I_{G_3}\bar{\alpha}_3 + m_3\, \bar{R}_3 \times \bar{A}_{G_3} \tag{24}$$

where the acceleration of the mass center of link 3 (which is coincident with pin B) is obtained from a kinematic analysis. The vector equation for point B can be written as

$$\bar{R}_B = \bar{R}_1 + \bar{R}_4. \tag{25}$$

Differentiating the X and Y components of this equation with respect to the input position, the first and second-order kinematic coefficients of point B, respectively, are

$$X_B' = -R_4 \sin\theta_4 \theta_4' \tag{26a}$$

$$Y_B' = -R_4 \cos\theta_4 \theta_4' \tag{26b}$$

$$Y_B'' = -R_4 \sin\theta_4 \theta_4'' - R_4 \cos\theta_4 \theta_4'^2 \tag{26c}$$

and

$$Y_B'' = R_4 \cos\theta_4 \theta_4'' - R_4 \sin\theta_4 \theta_4'^2. \tag{26d}$$

The X and Y components of the acceleration of point B can then be obtained from the relationships

$$A_{BX} = X_B'\alpha_2 + X_B''\omega_2^2 \qquad \text{and} \qquad A_{BY} = Y'_B\alpha_2 + Y_B''\omega_2^2. \tag{27}$$

The free body diagram of link 4 is shown in Fig. 9. The sum of the external forces in the X and Y directions can be written, respectively, as

$$F_{14X} + F_{34X} + F_{64X} = m_4 A_{G_{4X}} = 0 \tag{28a}$$

and

$$F_{14Y} + F_{34Y} + F_{64Y} - W_4 = m_4 A_{G_{4Y}} = 0. \tag{28b}$$

The sum of the external moments about the mass center of link 4 can be written as

$$(R_4 \cos\theta_4 F_{34Y} - R_4 \sin\theta_4 F_{34X}) + (R_{44} \cos\theta_4 F_{64Y} - R_{44} \sin\theta_4 F_{64X}) = I_{G_4}\alpha_4. \tag{29}$$

The free body diagram of link 5 is shown in Fig. 10. The sum of the external forces in the X and Y directions can be written, respectively, as

$$F_{15X} + F_{65X} = m_5 A_{G_{5X}} = 0 \tag{30a}$$

and

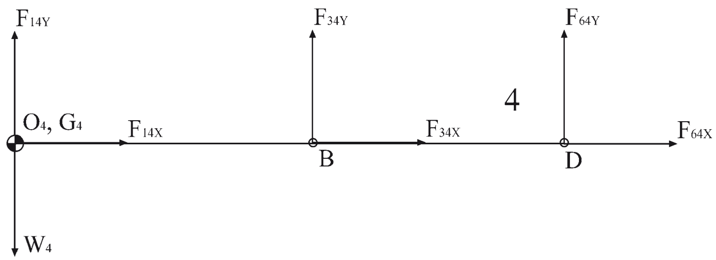


Fig. 9 The free body diagram of link 4

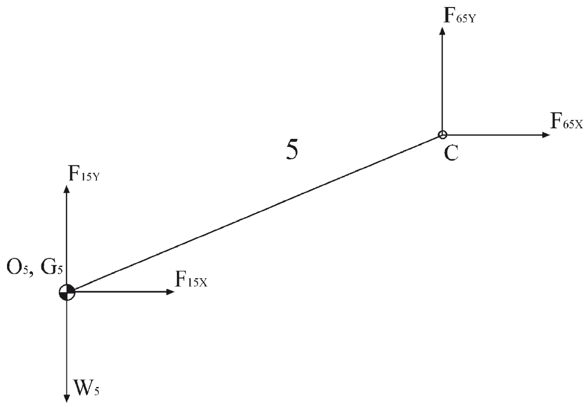


Fig. 10 The free body diagram of link 5

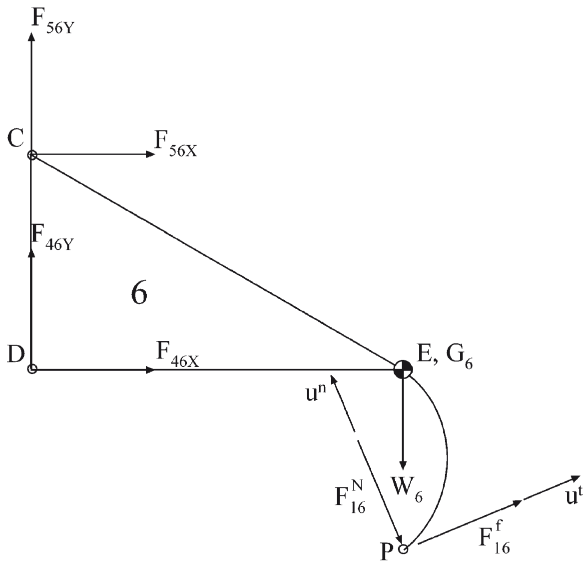


Fig. 11 The free body diagram of link 6

$$F_{15Y} + F_{65Y} - W_5 = m_5 A_{G_{5Y}} = 0. \tag{30b}$$

The sum of the external moments about the mass center of link 5 can be written as

$$R_5 \cos\theta_5 F_{65Y} - R_5 \sin\theta_5 F_{65X} = I_{G_5} \alpha_5. \tag{31}$$

The free body diagram of link 6 is shown in Fig. 11. The contact force between the ground and the blade point P is assumed to be known and the normal force is assumed to be acting downward, that is, in the opposite direction to the unit normal vector.

Also, the friction force opposes the velocity of point P, that is, the friction force is in the opposite direction to the unit tangent vector and can be written as

$$F_{16}^{f} = \mu\, F_{16}^{N} \tag{32}$$

where μ is the coefficient of friction. The sum of the external forces in the X and Y directions can be written, respectively, as

$$F_{56X} + F_{46X} - (F_{16}^{f})_P u^{tx} - (F_{16}^{N})_P u^{nx} = m_6 A_{G_{6X}} \tag{33a}$$

and

$$F_{56Y} + F_{46Y} - W_6 - (F_{16}^{f})_P u^{ty} - (F_{16}^{N})_P u^{ny} = m_6 A_{G_{6Y}} \tag{33b}$$

where u^{tx}, u^{ty}, u^{nx}, and u^{ny} are given by Eq. (18a). The sum of the external moments about point D can be written as

$$R_{DCX}F_{56Y} - R_{DCY}F_{56X} - R_{DEX}W_6 + \overline{R}_{DP} \times (-\overline{F}_{16}^{f} \bullet \hat{u}^{t} - \overline{F}_{16}^{N} \bullet \hat{u}^{n}) = I_{G_6}\overline{\alpha}_6 + m_6\, \overline{R}_{DE} \times \overline{A}_{G_6}. \tag{34}$$

The vector equation for the mass center of link 6 (which is coincident with point E) can be written as

$$\overline{\mathrm{R}}_{\mathrm{E}} = \overline{\mathrm{R}}_1 + \overline{\mathrm{R}}_{44} + \overline{\mathrm{R}}_{66}. \tag{35}$$

Differentiating the X and Y components of this equation with respect to the input position, the first and second-order kinematic coefficients of point E are

$$X_E' = -R_4 \sin\theta_4\theta_4' - R_{66}\sin(\theta_6 + 180 - \Psi)\theta_6' \tag{36a}$$

$$Y_4' = R_4 \cos\theta_4\theta_4' + R_{66}\cos(\theta_6 + 180 - \psi)\theta_6' \tag{36b}$$

$$\begin{aligned} X_E'' = &-R_4 \sin\theta_4\theta_4'' - R_4\cos\theta_4\theta_4'^2 - R_{66}\sin(\theta_6 + 180 - \psi)\theta_6'' \\ &- R_{66}\cos(\theta_6 + 180 - \psi)\theta_6'^2 \end{aligned} \tag{36c}$$

and

$$\begin{aligned} Y_E'' = &R_4 \cos\theta_4\theta_4'' - R_4\sin\theta_4\theta_4'^2 + R_{66}\cos(\theta_6 + 180 - \Psi)\theta_6'' \\ &- R_{66}\sin(\theta_6 + 180 - \Psi)\theta_6'^2. \end{aligned} \tag{36d}$$

The X and Y components of the acceleration of point E can then be obtained from relationships similar to Eq. (27).

The total number of unknown variables for the dynamic force analysis is 15, and there are 15 equations, see Eqs. (21)–(24), (28)–(31), (33) and (34). The solution can be obtained by writing the equations in matrix form and taking the inverse of the 15 × 15 coefficient matrix. However, to provide insight into the analysis, and as a check of the matrix inversion, the solution can be obtained from an inspection of the 15 equations. A possible rocedure is to solve Eqs. (31) and (34) for the internal reaction forces F_{56X} and F_{56Y}, Eq. (33a) for the internal reaction forces F_{46X}, Eq. (33b) for the internal reaction force F_{46Y}, Eq. (30a) for the internal reaction force F_{15X}, Eq. (30b) for the internal reaction force F_{15Y}, Eqs. (24) and (29) for the internal reaction forces F_{34X} and F_{34Y}, Eq. (28a) for the internal reaction force F_{14X}, Eq. (28b) for the internal reaction force F_{14Y}, Eq. (23a) for the internal reaction force F_{23X}, Eq. (23b) for the internal reaction force F_{23Y}, Eq. (22) for the hydraulic actuator force F_H, Eq. (21a) for the internal reaction force F_{12X} and Eq. (21b) for the internal reaction force F_{12Y}.

To illustrate the numerical procedure, consider $O_2 O_4$ = 34.0 cm, O_2A = 34.0 cm, O_4B = 36.0 cm, AB = 46.0 cm, O_4D = 61.0 cm, O_2O_5 = 11.5 cm, O_5C = 62.5 cm, CD = 46.0 cm, DE = 61.0 cm, EP = 38.0 cm, $\beta = 70^o$, $\psi = 90^o$ and the line EP is parallel to the line CD. The input link is rotating counter-clockwise from an initial position $\theta_2 = -10^o$ to a final position $\theta_2 = +20^o$, with an angular velocity and acceleration as shown in Figs. 12a and b, respectively. For the specified range of motion, the X and Y coordinates of the path of point P, obtained from Eq. (14), and the radius of curvature of the path, see Eq. (19), are as shown in Figs. 13a and b, respectively.

The velocity and acceleration of point P versus the input position are as shown in Figs. 14a and b, respectively.

The masses of the links are m_2 = 1.5 kg, m_3 = 2 kg, m_4} = 4 kg, m_5 = 2.5 kg, and m_6 = 25 kg and the mass moments of inertia of the links, about their respective centers of mass, are I_{G2} = 0.030 N m-s^2, I_{G3} = 0.045 N m-s^2 and I_{G4} = 0.075 N m-s^2 I_{G5} = 0.095 N m-s^2, and I_{G6} = 0.250 N m-s^2. When the blade is in the soil, that is, – 85 cm $\geq Y_P \geq$ – 115 cm, the coefficient of friction and the friction force at point P are assumed to be $\mu = 0.30$ and F_P^f = 100 N respectively.

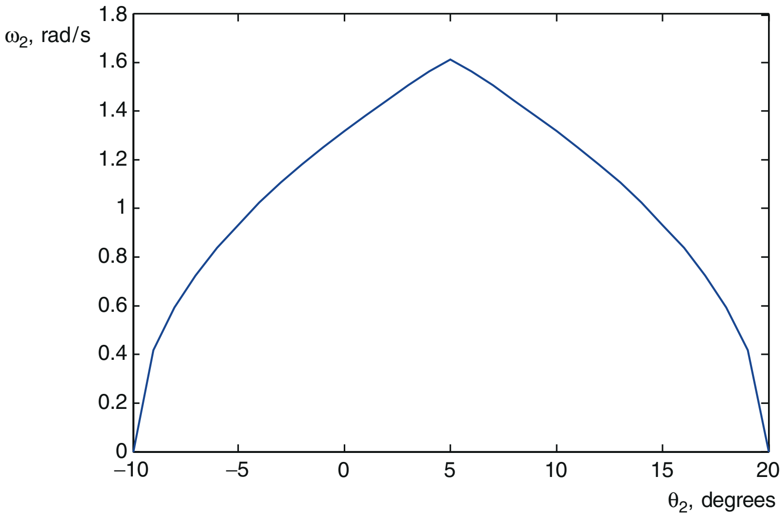


Fig. 12 (**a**) The angular velocity of the input link 2. (**b**) The angular acceleration of the input link 2

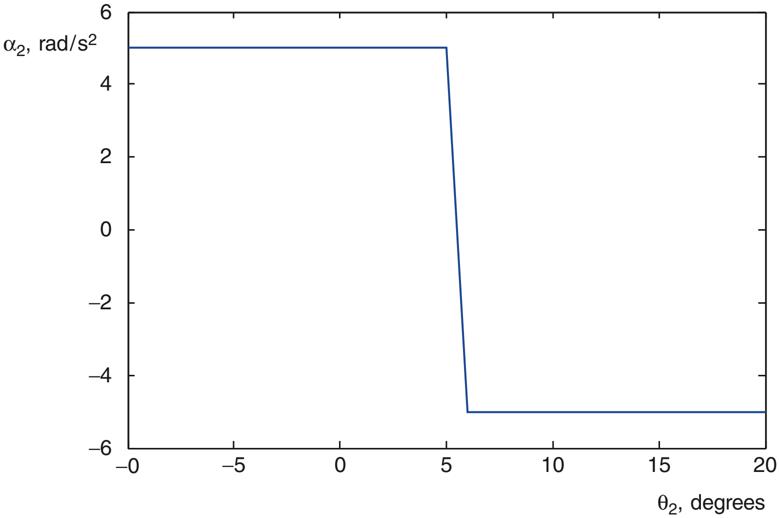


Fig. 12 (continued)

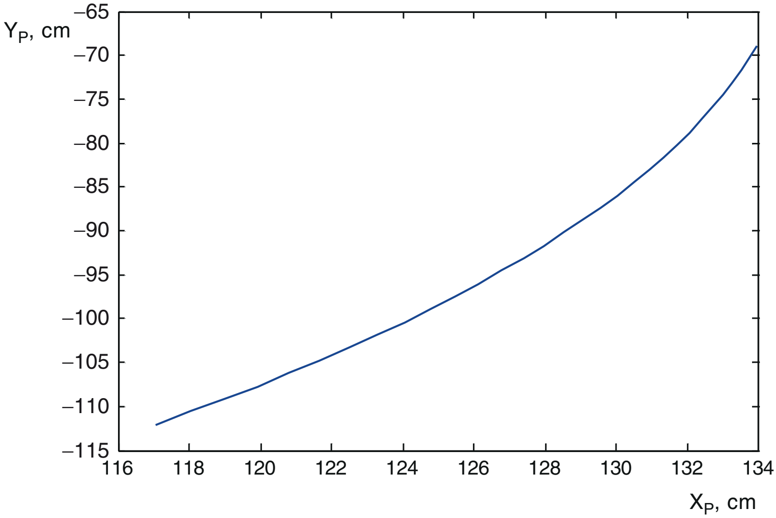


Fig. 13 (**a**) The X and Y coordinates of the path of point P. (**b**) The radius of curvature of the path of point P

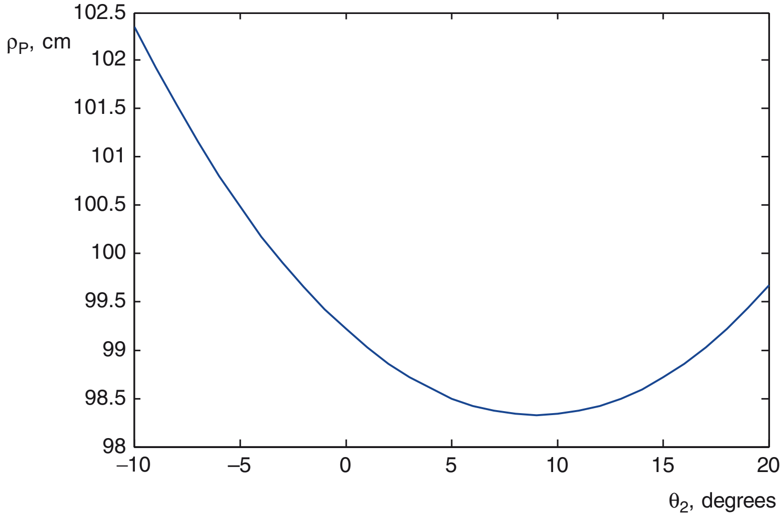


Fig. 13 (continued)

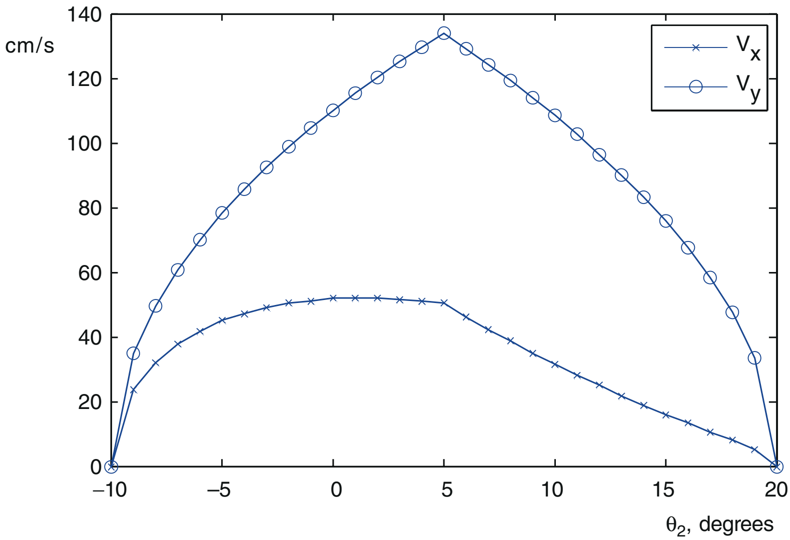


Fig. 14 (**a**) The velocity of point P versus the input position. (**b**) The acceleration of point P versus the input position

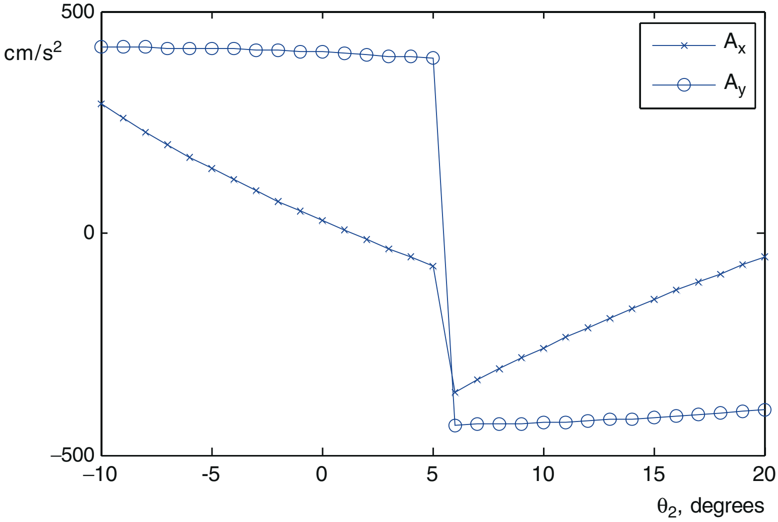


Fig. 14 (continued)

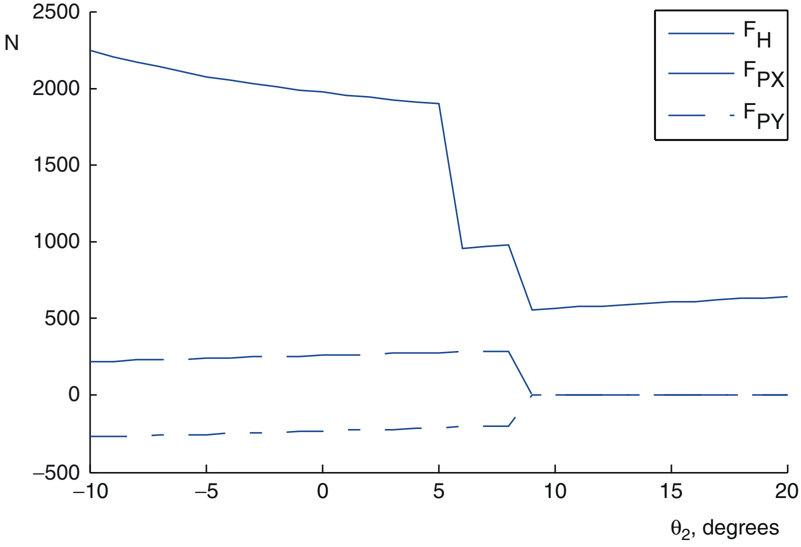


Fig. 15 The X and Y components of F_P and F_H

Due to space considerations, a complete set of numerical results for the dynamic force analysis will not be presented here. However, for illustration purposes, consider the force that is required by the hydraulic actuator to overcome the contact force on the blade at point P. The X and Y components of this force against the position of link 2 are as shown in Fig. 15. From the solution to the dynamic force analysis, a plot of the corresponding hydraulic actuator force against the position of the input link is also shown on the figure. It is worth noting that the numerical results of the force analysis can be used, for example, to demonstrate the influence of the link dimensions on the loads acting on the links of the three-point hitch and on the tractor. The results can also be used by the designer to optimize the link dimensions and to investigate the dimensions proposed by Ferguson in his original design. Also, the hydraulic actuator can be sized based on the maximum contact force that is expected at P.

Concluding Remarks

Henry George (Harry) Ferguson died at Abbotswood, Stow-on-the-Wold, Gloucestershire, in his bath about 8:30 am, Tuesday, October 25, 1960 (10 days before his 76th birthday). He had been suffering from a manic depressive condition and, over the years, this condition had become more severe. The doctor attending Ferguson said that in July, 1959, Ferguson was found in similar circumstances in his bath. On that particular occasion, the doctor had come to the conclusion that Ferguson was suffering from an overdose of barbiturate tablets. The pathologist and the coroner at Ferguson's inquest indicated that Ferguson had died from an overdose of barbiturate tablets but that there was no evidence to show whether the tablets were self-administered or ingested accidentally. Ferguson was cremated 3 days after his death on Friday, October 28.

Even in the last few months of his life, Ferguson was planning a new venture in tractor distribution in his native Northern Ireland. He saw the exploitation of land resources as the way to prosperity and lower prices. He had even argued in pre-World War II days that Nazism might have been contained by intensive cultivation of German soil. During his last few months, all his activities were centered on his car project which he regarded to be of fundamental importance. This project received tremendous publicity but remained shrouded in secrecy. One prominent motoring correspondent spoke of Ferguson as the man behind the car that never was. One of Ferguson's business associates said at the time that the car was a tremendous technical advance on anything seen so far and should be put on the market at the earliest opportunity. A motoring correspondent of a large newspaper said that competent observers had stated that Ferguson's car design secrets did indeed spell of unheard of efficiency.

In spite of his great gifts and rare personal qualities, Ferguson would not have been an easy partner to work with. In fact, he was an extremely difficult man. He had a fanatical attention to detail and insisted, for example, that his employees wear clean boiler suites and display white handkerchiefs. When Harry stumbled upon an idea, he had the vision and the tenacity to pursue it over many decades. He sought out people to pursue his ideas with him and he had the ability to inspire them to make contributions beyond their own talents. In most cases, he won from them uncompromising and long-lasting loyalty. It will never be known, however, how much his own intense individualism frustrated agreement with those in government circles who wanted to collaborate with him. Ferguson held very strange views on economics, believing very passionately in reducing prices so as to widen the market that he continued to do so regardless of the general inflation forces affecting his costs (Neufeld 1969). Negotiating for sales of his assets with Massey-Ferguson, on one occasion in 1953, he agreed to the toss of a coin to settle the difference between $16 million and $17 million. Alas, he called tails and lost the $1 million. Later he was presented with a cigar box with the tossed coin fixed on top and the engraving, "To our friend and partner Harry Ferguson, A gallant sportsman". His inventions, especially the three-point hitch, and his dedication to an affordable tractor, had a great influence on the agricultural economies of the world. His economic philosophy was guided by the belief that the best way to improve the total economy was through cutting the costs of production of agricultural products which control the cost of living. The measure of his success can be gauged by the fact that over 85% of all wheeled farm tractors produced in the 1960s were based on the Ferguson system or derivations of this system (Feilden 1970).

It is unfortunate that the relentless genius of Ferguson did not bring more opportunities for economic growth in the land of his birth. One of his greatest disappointments was the refusal of the Northern Ireland Government, on two occasions, to support his tractor project. Ferguson claimed that his love for Ulster was greater than his love for any other country on earth. He was proud to be an Ulsterman and it is most fitting that there are several plaques and monuments to him in his native land. There is a plaque on the farm house of his birth, in Growell, and another on the site of his original showroom which is now the Ulster Bank building, Lower Donegall Street, Belfast. The Ulster Folk and Transport Museum at Cultra has an early tractor and plough and a full-scale replica of his aeroplane. There is also a granite memorial to his pioneering flight on the North Promenade in Newcastle, County Down. Ferguson received an honorary degree of Doctor of Science from Queen's University, Belfast, in 1948, and an honorary degree of Master of Engineering from Trinity College, Dublin, in 1949. He was offered a knighthood on two occasions, by the Labor and Conservative Governments (Wymer 1961). The British Prime Minister, Sir Winston Churchill, proposed to Ferguson that he should be offered a knighthood and in November 1953 he received a formal letter from 10 Downing Street, London (the home of the Prime Minister). The letter asked if this mark of Her Majesty's favor would be agreeable with Ferguson. However, Ferguson declined the offer on the grounds that this honor should be reserved for people such as servicemen and statesmen whose financial reward for their labor is comparatively small. He believed they should not be given to businessmen or industrialists who have the opportunity to become famous or amass wealth and all that wealth can bring them. In his letter of reply to Churchill he wrote, "I fear I have seen, so often, the harmful effects of an Honors List for industrialists, that I believe I have come to the right conclusion when I ask that the Prime Minister would not submit my name to the Queen in this connection." He, among many others, greatly underestimated his accomplishments and contributions to Britain and the world. A knighthood would have been no less than this man deserved.

It is also unfortunate that the history books will tend to remember Henry George (Harry) Ferguson as a businessman who fought and won a David and Goliath legal action against the Ford Motor Company. This is a grave injustice, for Ferguson was a superb innovator and engineer who built up his business on the basis of very small capitol resources. Harry Ferguson revolutionized mechanized farming in the 1940s. His invention of the three-point linkage system meant that one tractor could be used to pull a variety of implements. Before this invention, farmers had to have a different tractor for different jobs. His system also brought greater safety and stability to tractors. He was the cofounder of the Coventry tractor manufacturing company of Massey-Ferguson. The TE20 tractor was built in Coventry, England, and reached production of more than half a million, with hundreds of thousands of successor models built at the plant for almost 50 years. It was fitting that in 2008, Coventry considered Ferguson for one of the first 10 names for the city's Walk of Fame. In 2006, the Northern Bank Limited, Northern Ireland, issued a 20 pounds sterling banknote with a portrait of Ferguson and the Belfast plough. On August 16, 2008, Growell opened a memorial garden, near the home of his birth, to honor his contributions to society. At the time of writing this article, plans are underway to commemorate the 100th anniversary of his first powered flight in Ireland in that small monoplane on December 31, 1909, at Hillsborough. Ferguson may not have soared very high that particular day, but his mechanical genius was to lift mankind to new heights.

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Patents filed by Ferguson can be located at: http://www.google.com/patents

Patents filed by Ferguson can also be located at the European Patent Office: http://ep.espacenet.com