Remote Hydraulic Circuits for Zero Turning Radius Mowers

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Abstract. Stationary and mobile auxiliary hydraulic circuits were developed for retrofit to an existing hydrostatic circuit for a zero turn radius (ZTR) lawn mower. Both circuits provide remote hydraulic quick connects for attachment of accessory implements powered by the existing ZTR hydraulic pump. The stationary circuit bypasses fluid flow to a wheel motor providing full, reversible pump flow to an auxiliary circuit. The mobile circuit places an accessory motor in series with the wheel motor to provide full, reversible pump flow to an auxiliary circuit. Proof and demonstration of concept were provided with a pull behind log splitter and a rear mounted landscaping blower. The remote hydraulic circuits allow ZTR mowers to serve as platforms and powerhouses for a number of cylinder- and motor-actuated implement and accessory applications.

Keywords. Remote hydraulic, lawn and garden attachments, zero turning radius mower, hydrostatic transmission.

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Introduction

The U.S. lawn and garden products & services market retailed about $21.5 billion in 2011, down slightly from $22.7 billion in 2007, with projected sales of $24.1 billion by 2016 (Alpert, 2011). Lawn and garden equipment accounted for 51% of the 2011 market at $10.9 billion, with outdoor power equipment constituting $7.7 billion of this; in 2011, 7.0% of U.S. adults purchased outdoor power equipment. It was estimated for 2011 that riding and tractor-type lawn mowers alone were responsible for about $3.2 billion in retail sales, although the report does not distinguish between ZTRs and conventional lawn tractors, or riders. In his report, Alpert (2011) states the following: "The hottest product in recent years has been the zero-turn (ZT) riding mower. Consumers and professionals alike have embraced ZTs for their speed, maneuverability, and fun."

Early hydrostatic drives on agricultural equipment were used for "stepless", "continuously variable" or "infinitely variable" transmissions (Hurig, 1963; Ruoff, 1965). In 1966 (Swedberg), a U.S. patent was issued for a hydrostatic transmission for small vehicles such as garden or home tractors. The variable displacement, reversible-drive, hydrostatic circuitry employed in this invention was very similar to that used in modern ZTR machines, although the patent does not suggest the use of dual, independent wheel motors allowing for integration of steering and propulsion. The design implied the use of a single hydraulic motor to drive the rear axle.

The next major developments for hydrostatic transmissions in small vehicles involved infinite position, foot-operated pedals for directional and speed control (Phillips, 1970; Fieber, 1970) – predecessors to today’s hand-operated control levers. Around the time of application of hydrostatic drives to riding lawn mowers and garden tractors, Kamlukin (1964) developed a joystick control mechanism for a belt driven machine. This was not the first joystick lever for vehicular control, but it was the first that combined controls for steering and propulsion into a singular joystick or lever – forward and backward motion for propulsion, left and right motion for steering. Deines (1972) took this concept several steps further, incorporating it with the hydrostatic drive, and also adding a second hydraulic motor, providing the first patent for a riding mower with independently operated wheel motors.

Hall (2007) indicates that hydraulics specialist Ray Rilling should be credited with development of the first ZTR mower in 1964 – the Excel Industries Model 36. However, Deines’ invention represents the first patent on record in this literature review. Regardless of whether Rilling or Deines is credited with conception, the ZTR mower as we know it today was developed in the mid- to late-1960s and has remained fundamentally unchanged since, with the exception of changing the physical configuration and location of components (e.g. deck, engine, caster wheels). Deines’ machine (Figure 1) included a front-mount, overhung deck; two (left and right) steering and control levers to operate the direction and speed of each wheel motor; and a rear caster wheel.

Figure 1. The father of the modern ZTR mower (Deines, 1972).
The greatest advantage of ZTR mowers over conventional riding mowers is inarguably their maneuverability and tight cornering abilities, providing the operator with a substantially increased effective field capacity. The hydrostatic transmissions that they employ allow directional changes and speed changes without adjusting engine speed or changing gears (Betz, 1991). ZTR mowers integrate the steering and drive systems with a hydrostatic transmission utilizing one or more hydraulic pumps to drive two wheel motors. A typical circuit is provided in Figure 2. Traditional transmissions utilize “pump and motor” or “split system” drives, which consisted of independent housings for the pump and wheel motor, connected by hydraulic hoses.

An integral drive unit was first patented for use in smaller vehicles such as riding lawn mowers in 1968 (Peterson). The integral drive unit contains the pump, wheel motor, gearing, and fluid reservoir in a singular block with fluid ported through drilled passages in the housing rather than through hoses. Although the fluid conduit differs, fluid circuitry in integral drives is similar to that of pump and motor drive units. It was not until about 30 years after its inception that the integral drive unit was adopted into the mainstream ZTR industry (Murray, 1997). These integral drive units were first introduced by manufacturers into residential or consumer models, but progressively they have made their way into commercial and professional machines.

The success of integral drives can be partly attributed to reduced assembly complexity, leading to increased manufacturing productivity and therefore lower retail costs. Snapper Inc. (McDonough, GA) executives reported that they could build integral drive machines three times as fast as pump and motor drive machines (Murray, 1997). Based on discussions between the authors and several industry representatives at the 2012 Green Industry & Equipment (GIE) Expo in Louisville, KY, commercial and professional ZTR models have been slower to abandon the traditional pump and motor units, presumably because of the reduced serviceability of integral drives. The general repair protocol for problems with the integral drives is replacement of the entire drive unit, whereas pump and motor drives provide the opportunity to replace only those drive components that have failed (Joe Whitlow, Anderson Outdoor Power Equipment, Anderson, SC, personal communication, June 2010).

The retrofit kit or original equipment manufacturer option developed in this project takes advantage of the arrangement utilized in pump and motor drives for ZTRs and makes available alternative fluid flow paths allowing the full flow developed by the existing pump to be used for tasks other than or in addition to rotating the wheel motor, providing opportunities for hydraulic power take-off similar to those for the agricultural tractor. This system relies on the ability to reroute the fluid flow between the pump and wheel motor and therefore cannot be implemented on machines utilizing integral drive units, with internal fluid porting and no hoses. There were more than one hundred ZTR models offered by more than thirty manufacturers in 2007 (Hall). While the general trend has been towards integral drive units, with, there are still a number of models with pump and motor drive systems that continue to allow implementation of the technology developed here. Existing machines sometimes make available remote hydraulic circuits for tasks such as deck lift, using the flow generated by the charge pump, although this does not take full advantage of the machine’s hydraulic power capabilities.
Objectives

- Develop cost effective circuits to utilize existing ZTR hydraulic power for auxiliary power supply.
- Develop and construct two operator-friendly independent circuit designs for stationary- and mobile-auxiliary applications.
- Construct and use sample accessories for testing of power take off circuits.
- Estimate retail costs of power take off circuit retrofit kits.

Materials and Methods

The stationary circuit (Figure 3) developed as a part of this technology utilizes a solenoid actuated, double selector valve (Model DS: Prince Manufacturing Corporation, North Sioux City, ND) to divert full fluid flow from the wheel motor to the remote circuit quick connects. A toggle switch is provided near the operator’s station to energize the solenoid, which shifts the valve into remote circuit operation. Similar to normal operation for propulsion and steering, fluid flow is reversible utilizing the machine’s existing steering control lever for directional and speed control. The arrangement of this circuit makes it useful for both cylinder and motor applications. During operation of this circuit, fluid completely bypasses the wheel motor, which allows the wheel motor to serve as a hydraulic braking mechanism to keep the machine stationary. Proof of concept for this circuit was demonstrated through the construction and use of a log splitter (Figure 4).

Figure 3. Stationary circuit for auxiliary hydraulic drive from hydrostatic transmission.
The mobile circuit (Figure 5) utilizes a two-position, four-way solenoid valve (Part Number 241-246: Dalton Bearing and Hydraulic, Blaine, TN) to place a pair of remote quick connects in series with the wheel motor. This allows for full fluid flow to be directed to the remote circuit while sequentially passing through the wheel motor as well. Inherently, this circuit does not lend itself to cylinder applications because at full extension or retraction of the cylinder, fluid would dump across the pressure relief valve in the hydrostat loop, eliminating flow through the wheel motor. It is therefore limited in practicality to rotary accessory applications where it is acceptable that the speed of the accessory motor be proportional to the speed of the wheel motor (i.e. higher travel speeds equate to higher accessory drive speeds). A momentary-ON or toggle-ON switch can be provided to energize the solenoid, depending on the nature of the auxiliary application. Reversibility of the accessory drive is allowed and can be accomplished by reversing the travel direction of the wheel motor while the circuit is energized. In the development of this technology, a circuit was also designed, but not tested, to provide unidirectional fluid flow through the accessory motor, regardless of pump flow and wheel motor rotational direction. Proof of concept for the mobile circuit was demonstrated through the construction and use of a landscaping blower (Figure 6).
Results and Discussion

One stationary remote circuit can be provided per wheel motor, allowing for two independent, stationary remote circuits per machine. Multiple mobile circuits can be added in series per wheel motor using a separate valve for each, however the sum of the hydraulic power requirements of all operations in series cannot exceed that generated by the pump driving that motor. The stationary circuit is capable of utilizing the full power capabilities of the hydrostat pump, those that would otherwise be delivered to the wheel motor, because flow through the wheel motor is fully diverted to the remote circuit when the solenoid is engaged. The mobile circuit is only capable of utilizing the power available at the pump, less that amount consumed at the wheel motor for propulsion, since the remote circuit is placed in series with the wheel motor. A schematic demonstrating application of both the stationary and mobile circuits on one pump and motor circuit is provided in Figure 7.

A rough cost analysis was conducted based on the prototypes constructed for testing the concept (ASABE, 2013). Minimum suggested list price, in 2012 U.S. dollars, would be $397 for a retrofit kit to include both
circuits, $192 for the mobile circuit alone, and $272 for the stationary circuit alone. Specific cost estimation guidelines for fabrication and assembly are outlined in the referenced ASABE handbook. Wholesale estimates for parts were estimated at 40% of retail and for raw materials at 70% of retail. Production costs were marked up 40% to obtain an estimated suggested list price. It should be noted that this estimate was not intended to be exhaustive or absolute; these costs would be reduced substantially with refinement of the prototypes developed for proof of concept. As estimated and with costs of ZTR mowers from $1800 to nearly $10,000, this add-on would constitute only about 5-20% of the cost of the mower.

As early as the mid-20th century, it was said that hydraulic power capabilities of tractors revolutionized their utility (Gulvin, 1953) and these circuits have the potential to increase the versatility of ZTR mowers in the same way. Since the mid-20th century, tractor hydraulics have come a long way, being standardized by the ASABE (ASABE, 2004; ASABE, 1988) and having a multitude of implements take advantage of hydraulic capabilities. Likewise, remote hydraulic functionality would allow ZTR machines to be utilized to supply power for many tasks in addition to cutting grass. Incorporation of the remote hydraulic circuits allows a ZTR machine to become a platform for any of a number of already existing implements used in construction, landscaping, and agriculture. Inclusion of the remote circuits could also represent the first significantly transformative development for ZTRs since Deines' (1972) patent.

The remote circuits provide similar capabilities as those on agricultural tractors, albeit at a lower power capacity. Depending on the hydraulic pump included on a given ZTR mower, hydraulic power availability for accessory drives will vary. For the machine used to test our prototype circuit, each wheel motor circuit provided an estimated available fluid power of 1.3 kW (1.7 hp). If commercialized, a standard is already in place for hydraulic couplers for lawn and garden equipment (ASABE, 2010), but will have to be reviewed for applicability since the remote circuits developed here are not dedicated remote circuits. Example applications for the stationary circuit developed as a part of this technology include: bucket loaders, concrete mixers, dump trailers, forklifts, generators, drawn implement lift cylinders, log splitters, post hole diggers, scrape blades, stump grinders, water pumps, winches, and wood chippers. Example applications for the mobile circuit developed as a part of this technology include: landscaping blowers, rotary brooms, snow blowers, sprayers, and rotary tillers. If this technology is commercialized, the most widely used application would likely be stationary circuits for use on dump carts.

Weber (2005) discusses several attachments available for zero turn mowers that can increase their versatility and extend their usefulness beyond the cutting season. In this article, it is asserted that landscape professionals, as professionals, should invest in the correct tool for the job, rather than multi-tasking a mower to complete jobs for which it is not designed. Weber also cautions about increased component wear as a result of employing attachments, an issue that would need to be addressed for the technology presented in this paper. Weber did not specifically address the consumer market, which could represent the most applicable market for the remote hydraulic circuits. The primary rationale for this is that a homeowner's ZTR could be used as a powerhouse for a number of tasks, replacing the internal combustion engines that currently power other equipment that the homeowner might own.

JRCO (Minneapolis, MN) and Mibar Products (Greenfield, WI) are two among a handful of companies that produce aftermarket ZTR attachments. There are also ZTR OEMs such as The Grassopper Company (Moundridge, KS) that have offer OEM attachments for their machines. Several ZTR OEMs and aftermarket manufacturers offer mulching kits, bagging kits, and vacuum kits. Generally speaking, the attachments offered by these companies utilize an additional internal combustion engine where rotary power is required and linear actuators where linear power is required. In most cases, utilization of the already existing hydraulic power capabilities of the machine would offer substantial benefit including, but not limited to one or more of the following: elimination of superfluous prime movers, cost reduction, maintenance reduction, enhanced control capabilities, and increased attachment capacities.

Agri-Fab (Sullivan, IL) is an example of an aftermarket attachment provider that has a number of products without power assist that could stand to benefit from hydraulic power provision, especially their dump carts and ground engaging implements. Some of their ground engaging implements and groomers are advertised in their marketing literature with concrete blocks for down force application and their rollers must be filled with water for down force application; all of these methods could be replaced with a hydraulic cylinder operated through the stationary circuit.

Although the authors assert a number of apparent and potential advantages of remote hydraulic circuit capability for ZTR and other hydrostat drive equipment, industry did not express a great deal of interest in the concept, at least not formally. In 2012, the Clemson University Research Foundation filed a provisional patent application for this technology (K. R. Kirk, H. F. Massey, B. T. Woody, U.S. Patent Application No. 61/597,965) and representatives from more than 30 of the largest attachment manufacturers, ZTR manufacturers, and
hydraulic component manufacturers were approached for feedback on the technology through email communication, and informal meetings at the 2012 Sunbelt Agricultural Expo (Moultrie, GA) and at the 2012 GIE Expo. The most obvious obstacle with commercialization of this technology is the presence of integral drives, which, as discussed earlier, do not allow implementation of this technology as currently designed. To compound this obstacle, integral drives are virtually ubiquitous in today’s consumer ZTR models – potentially the most applicable market for this technology.

Conclusion

Two independent circuits were developed and proven to provide remote hydraulic power utilizing the existing hydrostat system on a ZTR mower. Bolt-on retrofit kits could be made available at a retail prices of less than $200 for the stationary circuit, less than $300 for the mobile circuit, and less than $400 for both circuits. During the literature review for this paper, it was discovered that published documents on research and characterization of lawn and turf equipment capacities are extremely limited. Future work relative to this technology should include:

- Continued investigation of commercialization potential of these technologies should be conducted with industry manufacturers.
- If commercialization potential is realized, testing of the circuits should be conducted to better characterize hydraulic power capabilities, to assess the increased component wear and reduced life of OEM hydraulic components from use of the remote circuits, to assess additional reservoir or cooling capacity requirements, and to assess safety hazards of the technologies along with solutions to mitigate these hazards.

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References


