REMOTE CONTROLS ON AN AGRICULTURAL TRACTOR FOR PERFORMING ASAE/SAE FIELD UPSET TESTS

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Abstract:

A standard Ford[1] 4600 agricultural tractor was converted to remote control to perform ASAE/SAE field upset tests (rear rollover and side rollover). This paper discusses the engineering process to develop a remote-controlled tractor in determining the critical parameters of operation, to choosing appropriate actuators, designing the circuitry to control them, installing the actuators on the tractor, testing the system for functionality and then conducting numerous overturn tests. The system uses off-the-shelf components for simplicity, replaceability, and economic concerns. The remote control system has withstood 21 tests to date with no failures and will continue to be used for at least three more years of testing.

Keywords: ROPS, remote control, tractor safety, rollover, overturn

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[1]Mention of any company name or product does not constitute endorsement by the National Institute for Occupational Safety and Health.

Introduction

The goal of this project is to use a standard Ford 4600 tractor to conduct overturn tests conforming to ASAE/SAE standards. The National Institute for Occupational Safety and Health (NIOSH), Division of Safety Research in Morgantown has designed an automatically deploying ROPS (rollover protection system) and needed a tractor to test the concept. Since the tractor will actually be rolled for the tests, the tractor needed to be made remote-controlled to prevent injury to the operator. The wireless remote control system chosen controls the functions necessary to conduct the tests. The functions normally used to control a tractor are the steering, clutch, brakes, throttle, fuel shutoff, engine start, and transmission gear selection. Early in the design process it was decided that gear selection could be done manually prior to each test. The only proportional function necessary is steering to control the tractor during overturn tests and routine maneuvering. All other functions can be on/off with the throttle having multiple positions. The rate of engagement of the clutch is critical to ensure successful starts in higher gears and to avoid excessive clutch slippage.

Determination of Critical Parameters

The critical parameters were determined by simple testing procedures. The forces/torques required to disengage the clutch, engage the brakes, change the throttle position, change the fuel shutoff position, and rotate the steering wheel were determined with a spring scale. The necessary strokes associated with each function were measured. The following table includes all measured critical parameters for the tractor functions.

Table 1. Critical Tractor Parameters

Function	Force	Stroke
Clutch	43 lbs (191 N)	6 in minimum, 7 in maximum (15.2 - 17.8 cm)
Brakes (L+R)	40 lbs (178 N)	3 in (7.6 cm)
Throttle	4 lbs (18 N)	1.75 in (4.4 cm)
Fuel Shutoff	4 lbs (18 N)	1.25 in (3.2 cm)
Steering (torque with engine running)	30 in-lbs (3.4 Nm)	4 turns lock to lock

Hardware Selection/Design

The next step was to find actuators that could meet the requirements found listed in table 1. The clutch and brake actuators could be similar except for different strokes, and built-in limit switches would simplify installation and control. The desired voltage for the actuators was 24 V dc to keep the current draw minimal. The clutch actuation speed is critical and after finding a possible actuator, the slowest available speed of 1.13 in/sec (2.87 cm/sec) was tested on the tractor to be sure the engine would not stall in higher gears using this engagement speed. The overall lengths of the actuators were also critical to ensure adequate space for installation. Duff-Norton Mini-Pac actuators fit all parameters and provided 100 lbs (445 N) of force while only drawing 3 amps. The limit switches are adjustable and sealed in the actuator housing. The units incorporate a rugged jack screw for motion (see Figures 1, 2).

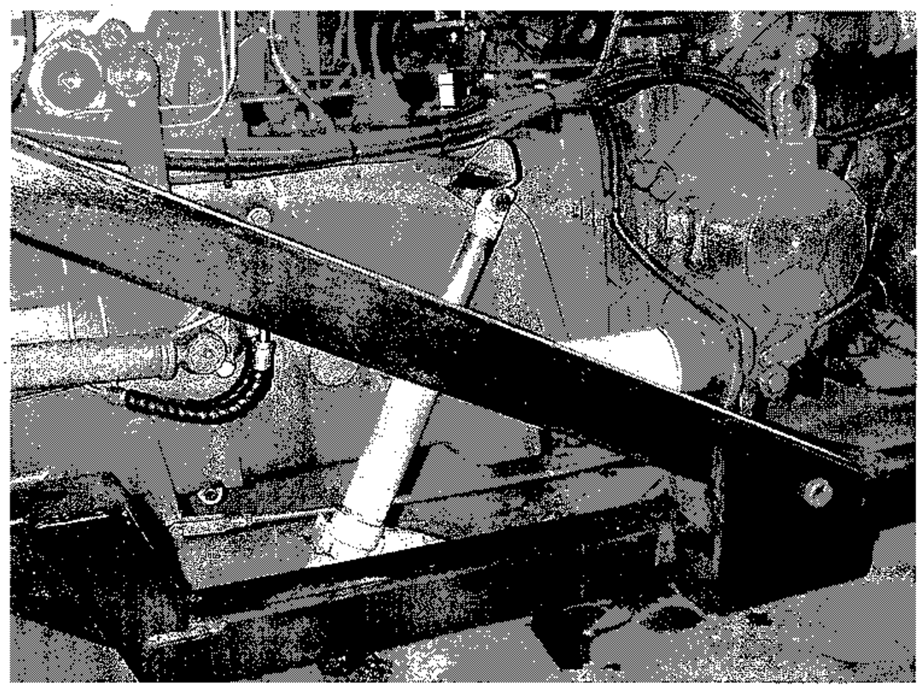

Figure 1. Clutch actuator.

As well as meeting force and stroke requirements, both the throttle and fuel shutoff actuators must return to idle/off when control power is lost to avoid any unsafe conditions (i.e. runaway tractor). This criteria was accomplished by using actuators that release on power loss and springs that return function controls to safe positions. The throttle actuator, manufactured by ADDCO, is powered by 24 V dc and has four adjustable positions controlled by a module mounted to a plate under the dash panel. Idle, maximum RPM, and two intermediate steps can be set independently. When power is cut off (emergency stop, receiver loss of signal, or manual shut off), the actuator releases and the spring of the throttle arm returns the system to the idle position.

The fuel shutoff is handled by a Trombetta solenoid that is actuated when the engine starter is engaged (see Figure 3). If the power is cut off, a spring pulls the fuel shutoff arm to the off position.

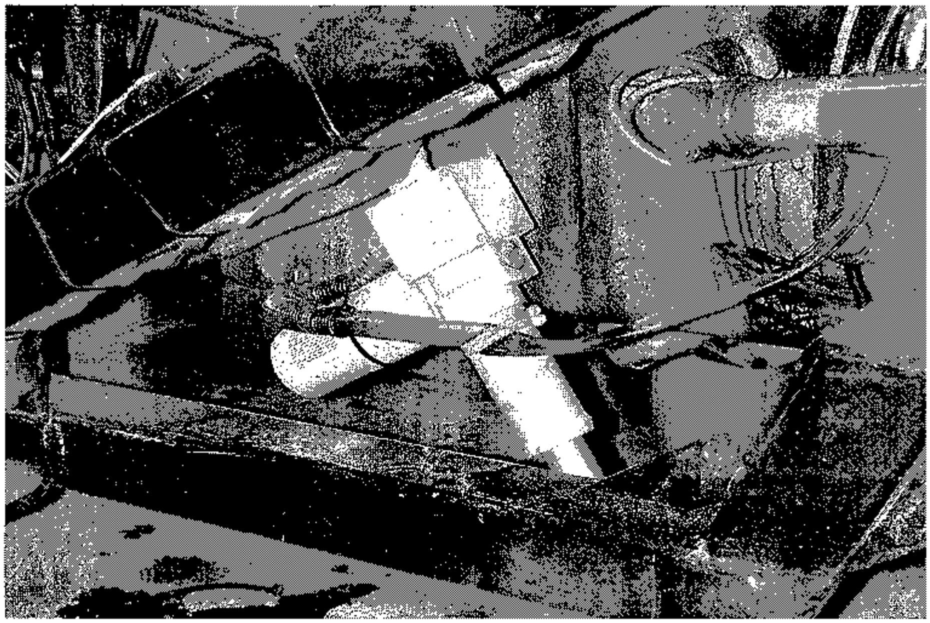

Figure 2. Brake actuator.

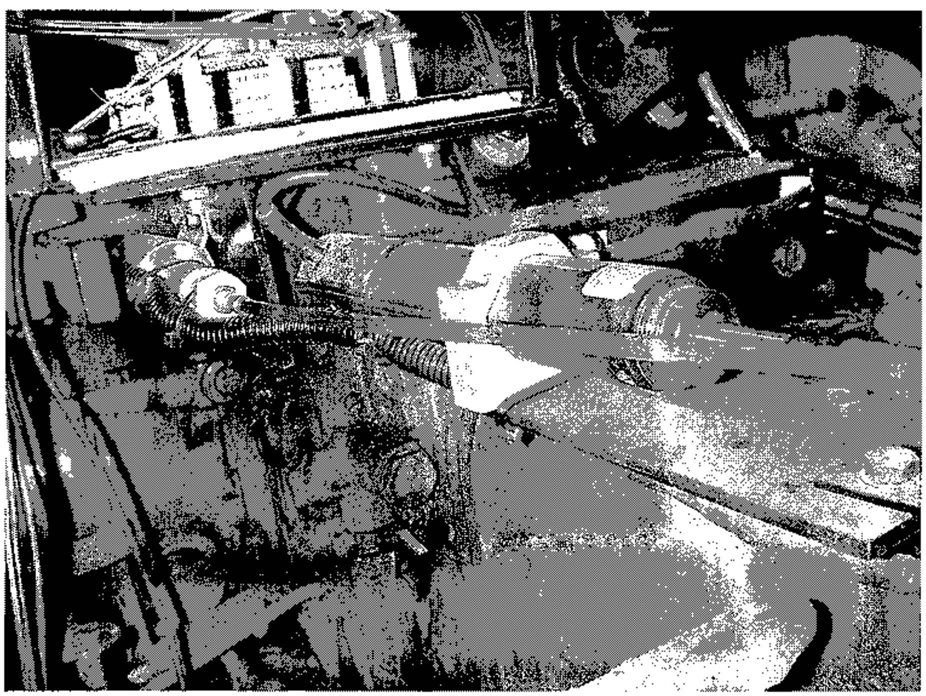

Figure 3. Throttle and fuel shutoff actuators.

Steering control proved the most challenging of any individual remote function on the tractor. Basic requirements included the following:

- Steering control resolution on the order of a few degrees
- Rotation range capable of maximum steering gear limits
- Fast and precise control for operation at high speeds (10 mph +) (16 kph+)
- Ability to readily convert back to manual control
- Rugged enough to withstand multiple rollover tests
- Price range of $2,000 -$3,000 in materials, for complete steering system

Several methods were initially considered, including hydraulic or electric actuators linked directly to the steering gear and an electric motor driving the steering column shaft. Ultimately, an electric positioning motor coupled to the steering shaft through sprockets and a chain was chosen. This approach is the most practical, since it leaves the original power-assisted steering system intact and is compatible with the power and control sources used for other remote functions on the tractor. In simplest terms, the remote operator steers the tractor by turning a knob on the transmitter requesting a steering motor position. An on-board receiver causes a corresponding rotation of the steering wheel shaft on the tractor.

The specific system used on the tractor includes an API DM-2205i-AE controller, powering an API three-stack NEMA 34 stepper motor with a Micron 10:1 planetary gear head, coupled to the steering shaft through a 0.5 in (1.3 cm) roller chain. The system can generate the necessary torque and speed in a compact package, which allows wide flexibility in position, speed, and range control. The system is also priced within the project budget. A few important specifications of the steering control are shown below:

- The controller is software programmable and can access multiple programs from memory
- The controller has an analog input compatible with the 0 to 10 V dc steering control signal available from the on-board radio control receiver
- The controller accepts 24 to 74 V dc main input power, 36 V dc nominal is used
- Torque available at the gear head output is 130 in-lbs (14.7 Nm) (limited by 36 V dc input)
- Maximum rotation speed at the gear head output is 0.4 rps (limited by 36 V dc input)
- Rotation resolution at gear head output is 0.8% of full rotation range, e.g. 8.4 degrees for 3 revolutions full range (limited by analog control input)
- The chain drive uses a 1:1 ratio (0.5:1 to 2:1 available with sprocket changes)

The motor/gear head assembly is mounted between the operator's seat and the shift control levers, with the drive chain running to a sprocket on the steering wheel shaft (see Figure 4). The location does not interfere with manual operation of controls, or vertical seat travel. To supply 36 V dc to the motor controller, an additional 12 V battery was placed in series with the 24 V dc source used for other actuators. Switches near the motor allow the user to select one of several

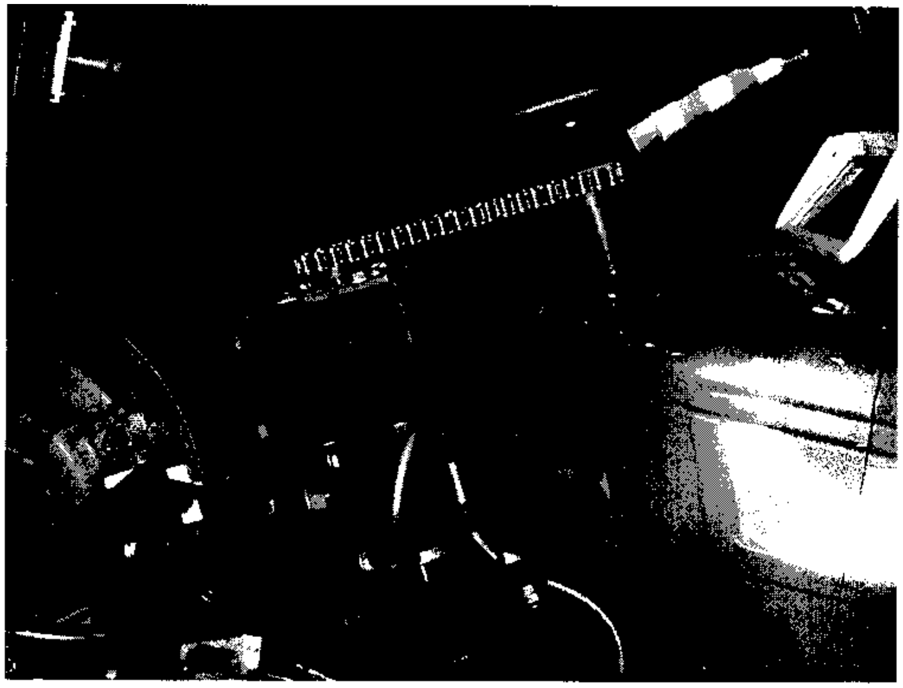

Figure 4. Steering system

steering programs preloaded into the controller memory, or disable the motor power completely for manual steering.

The motor and controller are an open loop system, that is, there is no feedback to the controller of actual motor position. This reduces complexity, but does require proper initialization each time the system is powered up. For remote operation, before any on-board systems are energized, the steering control switch is set to "remote", the steering program is preselected (via a rotary switch), and the steering gear on the tractor is manually aligned straight ahead. The transmitter is energized first, with the steering control knob centered (corresponding to 5 V dc output at the receiver). The tractor main power system is then energized. At this point, a delay relay isolates the steering motor from the controller for several seconds to allow the radio link to synchronize, the controller to initialize, and the 5 V dc steering control signal to stabilize. The initial condition resulting from this sequence is the steering referenced to straight ahead for an analog input of 5 V dc to the controller, ½ full travel to the left for 0 V dc, and ½ full travel to the right for 10 V dc. This relationship will be maintained unless the motor is mechanically stalled.

The programs for the steering control are assembled in a companion PC software package, APImate, and uploaded to the motor controller. They are essentially short code sequences that initialize basic controller settings, execute loops that monitor changes in the 0 to 10 V dc analog input, and send motion commands to the motor based on these changes. For work thus far, two programs have been used. One gives a full range of 1½ steering wheel revolutions, and the other three full revolutions. Because control resolution is based on full rotation range, the 1½ revolution program gives more precise control and better operator "feel" for the steering, and so is used for the overturn tests where accurate steering is important. The three revolution program offers less accurate control, but is more suitable for tight maneuvers.

A few other points about the system should be noted. Since the operator has only visual feedback for tractor control, the steering wheel spoke aligned to 12 o'clock for straight travel has been marked for high visibility. This simple feature provides a fast, continuous, and very effective update of steering gear position for the operator, visible at distances of several hundred feet. For a drive system of the type used here, if the load exceeds available torque, the motor simply stalls. This does not harm the motor under normal conditions, and is an advantage since it essentially eliminates the danger of damaging drive components if unusual steering resistance is met. Such resistance can happen when the steering gear is not initially centered properly and is subsequently driven to the stops, or if the steering drive is activated without the tractor engine running to provide power steering. One drawback to the system is the tendency of the software-based controller to remember each change in the analog control voltage and execute the corresponding steering moves in sequence. This means that an inadvertent over shoot in rotation of the steering control knob by the operator will likely cause a brief oversteer at the tractor. Although undesirable, the effects of over steering can be minimized through practice.

The radio system required for the tractor needed to have a minimum of four on/off channels and one analog proportional channel and preferably be industrial rated. The frequency had to be interference tolerant and have a range of at least 1,000 feet (305 m). A fail-safe condition was also needed that would drop out the actuator relays in the receiver and return them to safe positions if the emergency stop was activated or the receiver lost signal. The radio system chosen is a Futaba VSD-2001 that operates at 900 MHz spread spectrum at <= 1 watt RF output. The range is up to one mile or more with six discrete on/off channels and one analog proportional channel. The receiver is powered by 24 V dc. The relays in the receiver are opened and the analog channel goes to 0 V dc within 500 milliseconds of the receiver detecting a corrupted signal. A security feature of the system is a 16 bit ID code with over 65,000 discrete codes. The receiver is mounted to a plate with rubber shock isolators with the antenna protruding through the hood of the tractor (see Figure 5).

The on board control circuitry is designed to fail to safe conditions by returning the throttle to idle, shutting off the fuel, and applying the brakes. The different scenarios under which this could happen are: emergency stop, loss of power to the receiver, loss of signal to the receiver caused by interference, transmitter failure, or out of range. Also, if the clutch is disengaged or the brakes are applied, the throttle returns to idle.

Four sealed lead acid batteries are installed on the tractor. One is used solely to start the tractor and power the overturn sensor and instrumentation. The other three are used to power the actuators (steering, brakes, clutch, throttle, and fuel shutoff). Each battery has a dedicated charger to maintain a charge when the tractor is stored. One plug on the rear of the tractor

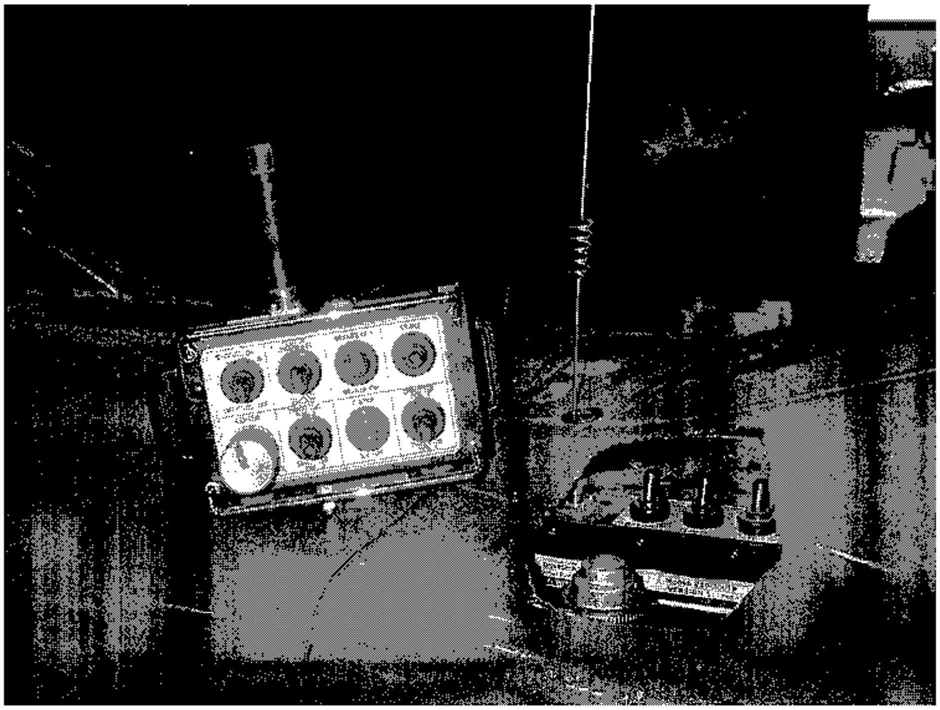

Figure 5. Radio system.

powers all of the chargers. There is a master disconnect switch for the 24 V dc power system and a key switch for the starter circuitry.

The on board control circuitry box is located under the dash panel where the large original fuel tank normally resided. All of the actuator power relays, fuses, and the steering controller are located inside the control box. The box is mounted on rubber shock isolators mounted to a plate (see Figure 6).

The large original fuel tank was replaced with a one gallon fuel tank to make room for the receiver and control circuitry box, as well as reduce the spill potential during rollovers. The vent for the fuel tank is routed in a large loop to further reduce the possibility of a fuel spill. The original exhaust system was rerouted and mounted below the hood line to protect it. A standard automotive muffler and exhaust pipes were used.

A roll cage was designed to protect the hood and front bodywork without adversely affecting the tractor roll characteristics. The roll frame provided mounting points for the clutch and brake actuators and also two of the batteries. Attachment points for the roll cage are existing threaded and through holes in the main tractor castings. Most of the roll cage is constructed of 3-in x 3-in x .25-in (7.6 cm x 7.6 cm x 0.6 cm) square tubing. A removable section of frame was added to the front to protect the front axle assembly during side rolls (see Figure 7).

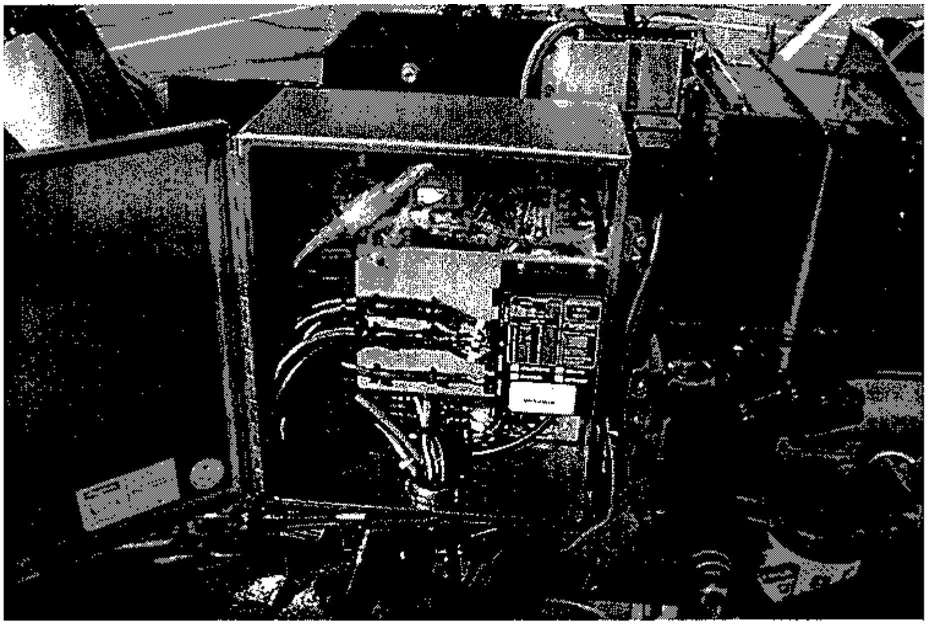
Figure 6. Control circuitry box.


Figure 7. Roll cage.

Performance in ASAE/SAE Field Upset Tests

To date, a total of 21 roll tests have been conducted at PRL. The remotely controlled tractor's performance in rear rollover tests has proven to be routinely satisfactory, with no damage to the tractor. The lack of damage can be attributed to the slow speed and limited impact to the rollbar. The side rollovers, to date, have proven to be destructive to the tractor. It is believed that this increased damage is due to the increased speeds and effects that the current side rollover configuration has on how various parts of the tractor impact the ground. In one instance, the left front wheel, axle, and steering gear parts were crushed, requiring $1,400 in repair parts. A removable section was added to the roll cage to protect the front end from similar damage in subsequent side rolls. The next side roll revealed the next weakest area which was the rear wheel assembly. Four out of eight adjusting clamps on the adjustable rear wheel broke on impact. However, the remote control components have survived all 21 overturns without failure.

Conclusions

The remote control system has proven to be reliable, robust, and inexpensive using off-the-shelf components for performing ASAE/SAE field upset tests. There have been no control system failures to date. The radio system has never encountered sufficient interference to impair control of the tractor or shut down due to it, and the range of the radio has been sufficient on all occasions. All other components have withstood the shock and vibrations during the testing without a failure. Research plans call for the use of the remote control system for at least another three years for rollover testing of various ROPS. In addition to the application of using the remote control system for rollover testing of a farm tractor, the system could also be applied to the operation of other mobile equipment that must be remotely controlled because of safety concerns for the equipment operator. For other applications, the actuators may be different depending on the application, but the overall system and radio could be used as designed for the tractor.

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