Dynamic Performance of the Mechanism of an Automatically Deployable ROPS

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Abstract

The mechanism for an automatically deployable ROPS (AutoROPS) has been designed and tested. This mechanism is part of an innovative project to provide passive protection against rollover fatality to operators of new tractors used in both low–clearance and unrestricted–clearance tasks. The device is a spring–action, telescoping structure that releases on signal to pyrotechnic squibs that actuate release pins. Upper post motion begins when the release pins clear an internal piston. The structure extends until the piston impacts an elastomeric ring and latches at the top position. In lab tests the two–post structure consistently deployed in less than 0.3 s and latched securely. Static load tests of the telescoping structure and field upset tests of the fully functional AutoROPS have been successfully completed.

Keywords. *ROPS, Passive protection, Automatic safeguard, Design, Testing*.

At least 132 work–related deaths per year occurred in the U.S. due to farm tractor overturns between 1985 and 1992 (Myers and Snyder, 1995). These overturns are by far the major source of fatal injury in the agricultural industry. Rollover protective structure (ROPS) use is increasing (Zwerling et al., 1997), but the number of overturn–related fatalities per year has not been declining significantly (NSC, 1997). ROPS can be particularly effective if seatbelts are worn (NSC, 1985). There are still some tasks, such as orchard work and barn cleaning, that cannot be performed with a rigid ROPS mounted to the tractor. Between 20% and 30% of tractors manufactured since 1978 are reported to be operating without ROPS (Myers and Snyder, 1995). Innovation is needed to increase the use of life–saving ROPS within this portion of the tractor population. Passive protection, with ROPS that can automatically move from a lowered to a raised configuration, is needed for tractor work that includes low–clearance operations.

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An innovative concept to answer this need was formulated at the Division of Safety Research, National Institute for Occupational Safety and Health (NIOSH). It is an automatically deployable, telescoping ROPS (AutoROPS) suitable for farm tractors. Technology innovations of this type have recently been developed for protecting drivers and passengers from the overturn hazard on convertible automobiles (Mercedes–Benz, 1995; U.S. DOT, 1989). The newly conceived NIOSH AutoROPS is signaled to rise automatically to its protective position before the overturning tractor contacts the ground. Of course, the protected volume that the ROPS provides depends on the operator being held by a seatbelt within the protected volume during an overturn. A tractor equipped with this device can be operated with the ROPS in its lowered configuration, either in low–overhead clearance areas where rigid ROPS interfere with tractor movement or in open–terrain areas.

The signal that initiates the raising of the structure can be provided by an electrical, optical, mechanical, or other sensing device that can reliably detect tractor dynamic operating parameters indicating imminent tractor overturn. The complete system for the AutoROPS concept consists of: a telescoping two–post structure, two large compression springs, a pyrotechnic release mechanism, a latch mechanism, and a sensor that detects when an overturn is about to happen. A self–contained hydraulic retract cylinder resets the device when the tractor use changes from unrestricted clearance tasks to low–clearance operation. Resetting can also be performed after periodic verifications of functionality or after deployments in near–overturn events. During the prototype development, there have been no occasions when it was necessary to reset the device because of inadvertent deployments due to system malfunction. During regular use of an AutoROPS in the future, if the device should deploy due to a system malfunction, the unit would need to be repaired, and not just reset, before further use.

Automatic operation overcomes the major shortcoming of manually adjustable ROPS, namely that their deployment depends on the actions of the tractor operator. Human strength limitations or safe behavior errors (forgetting to deploy or deciding not to deploy) could result in a manually adjustable ROPS not being deployed at a critical moment. The phase of the automatic ROPS (AutoROPS) development reported here is the design, fabrication, and proof–of–concept testing for the mechanisms that release the structure, raise it, and latch it in its deployed configuration. Subsequent proof–of–concept tests will be conducted on the strength of the new structure and sensor sensitivity to imminent overturn.

Description

Spring–Action Telescoping Structure

Design of the two–post telescoping structure was facilitated by use of finite element analysis (FEA) and computer–aided design (CAD) software. One of the main design parameters was that the deployment distance of 59.05 cm (23.25 in) must be traveled in less than 0.3 seconds (Baumann and Wunsche, 1990). Plain carbon steel seamless tube was the material selected for fabricating the structure. At the base of the sliding upper post is a cylindrical piston that contains engagement slots for the release pins. One portion of the FEA was modeling the reaction of the sliding–fit joint with respect to SAE J2194 (*SAE Standards*, 1997) test loading on the raised structure. The main compression spring is made from 11.89 mm (0.47 in) diameter stainless wire and has a 4.38 N/mm (25 lb/in) modulus.

Release Mechanism

Pyrotechnic squibs provide the force needed to simultaneously disengage two release pins that hold each post of the structure in the retracted configuration (fig. 1, right side). A 1.2 amp current of 2 ms duration ignites an initial 551.52 kPa (80 psi)/10 cc pyrotechnic gas expansion. A release pin is attached to a disk that is forced outward by the gas pressure acting in an expansion chamber. Each release device must reliably extract its pin from the pistons that hold the main springs compressed.

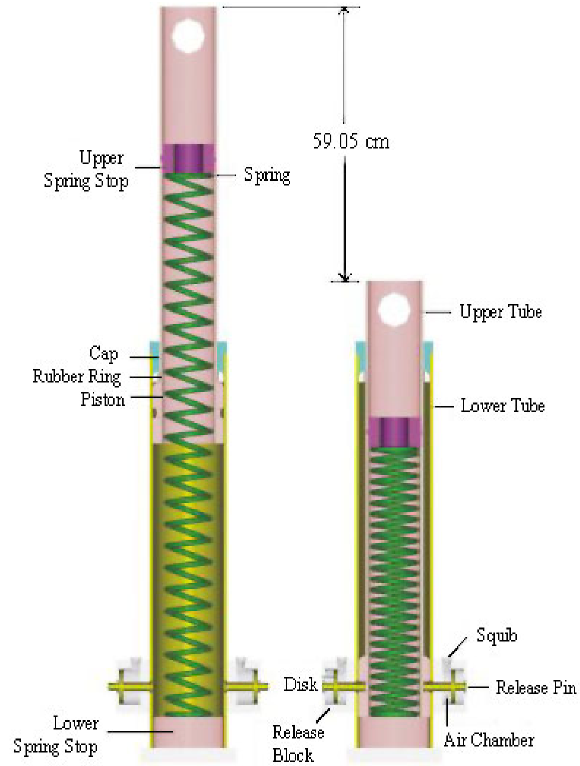

Figure 1. AutoROPS structure and mechanism.

Latch Mechanism

Two spring–loaded (8.75 N/mm (50 lb/in)) pins on either side of each base post snap into place underneath the upper post to lock it into the deployed position (fig. 1, left side). The pins (not shown) slide under the piston. These latch pins support the structure, especially for loading in–line with the posts. Linear bearings and a keyway were added to guide the pins after they failed to engage in some initial tests. During these initial tests, it appeared that contact with the piston as it moved perpendicular to pin travel caused misalignment and failure to latch. Reliable latching is critical to ensure that the structure is locked into the deployed position during an overturn.

A rubber ring was designed and glued to the bottom of the cap to absorb the energy of the piston impact. A detailed study was performed on the material (Howard, 1998). This elastomeric ring functions to absorb the impact and slow the rebound of the piston to give the latch pins time to move into place.

Retract Cylinder

A 28.58 mm (1.13 in) bore by 60.96 cm (24 in) stroke hydraulic cylinder is base–mounted to a manifold block. The cylinder fits inside the spring. Ports in the mounting block direct hydraulic fluid to ports at both ends of the retract cylinder. A two–position, manually levered valve controls the hydraulic flow for raising and lowering the upper structure.

Proof–of–Concept Tests

To determine the time required to extend and latch the structure, a Northern Digital Optotrak Motion Monitor was used to track the location of two strobing LEDs attached to the structure. One LED was attached at the top of the sliding post, the other on the base post. LED position was sampled at 400 Hz. An A/D card in a Fieldworks portable computer routed the Optotrak position data to a log file. Video recordings were made of the latching action to verify that there was no rebound before latching. For safety during testing, a retaining structure was built to constrain the structure if it should fail catastrophically during a release.

Results

Single–Post Release

On May 28, 1998, the AutoROPS release mechanism was successfully tested at the West Virginia University (WVU) Mechanical and Aerospace Engineering labs by the NIOSH/WVU project team. This was the first time that the mechanism had been released at full speed from its normally retracted position. The initial data indicated a travel time of about 160 ms, well within the design parameter. The energy releases of the pyrotechnic squibs and the compression spring extension took place without any unexpected consequences. The components of the structure showed no visible signs of failure when the device was disassembled. A videotape of the test also indicated satisfactory releases. No latch pins were used in this test.

Single–Post Latching

On June 22, 1998, ten full–deployment releases were conducted to evaluate the effects of normal deployment loading on the two latch pins and to determine if the latch pins completely engaged. Loading effects on the pins and the holes they move in were measured with a micrometer. The Optotrak was configured to measure the position of one latch pin during the course of each engagement cycle. Videotaping was conducted that focused on the movement of the top of the structure at its latched position. The tests were run in two sets of five releases, with the latch mechanisms disassembled and examined after each set of five releases. Only one release pin held the structure in the pre–deployment configuration. A manual pull on a cord attached to this pin accomplished each release. The findings were:

First five releases:

- Full latch pin engagement was achieved on all five releases.
- One pin rotated approximately 30º on one test. This pin showed a shallow indentation where the piston struck the extended pin.
- Slight chipping was seen on the tips of the pins. This surface tracked along the upper structure and piston during deployment.
- No deformation of pins or holes was indicated from micrometer measurements.

Second five releases:

- Full latch pin engagement was achieved on four releases. Videotape showed that there was rebound before latching on three of these releases. The structure failed to latch on one release.
- Some gouges on the piston surface were seen, possibly occurring during rebounds.
- No deformation of pins or holes was indicated from micrometer measurements.

Based on the unsatisfactory latching events, a new latch was designed that did not have the shortcomings of the initial design. These shortcomings were that (1) the latch pin did not have sufficient linear support, and (2) the pins rotated such that the rising piston did not contact the flat, tapered surface of the pin. The new design had (1) a linear bearing with longer bearing length and (2) a keyway and key to prevent the pin from turning. On October 15, 1998, ten latching cycles were performed with the new latch. All engagements were successful. The videotape showed no rebounds before latching.

Two–Post Release and Latch–Up

On December 9, 1998, the complete mechanical prototype for the AutoROPS was tested in the lab. A single squib on each post was ignited with a common signal. Four releases were conducted. Release–at–signal was achieved on all tests. Latching occurred on all tests and was verified by videotape. Three rise time measurements (table 1) were recorded. Test 1 data were not complete due to the data log file for the Optotrak opening too late. This problem was easily corrected in subsequent tests.

Table 1. Recorded deployment times.

Test	Rise time (ms)
1	—
2	205
3	165
4	165

Discussion and Conclusions

The modified deployment mechanism of the new AutoROPS was found to operate as intended during laboratory testing. Rise time was well within the 300 ms design parameter. Static load tests of the telescoping structure (Etherton et al., 2002) and field upset tests of the fully functional AutoROPS (Powers et al., 2001) have been successfully completed. Field testing following the SAE J2194 (*SAE Standards*, 1997) upset test requirements will be conducted next. It appears that a single squib on each post provides sufficient force to pull a single release pin on each post.

This device, in conjunction with the wearing of seatbelts, is very important to public health since tractors are the machine most frequently involved in occupational fatalities in the U.S. (Pratt et al., 1996), and ROPS are a highly effective way to prevent such deaths (Thelin, 1990). In a recent study in New York, 68% of tractors with ROPS had seatbelts (Kelsey et al., 1996), but it is estimated that both seatbelts and ROPS are used in only 54% of tractor operation time (Myers and Snyder, 1995). This invention will permit tractors that have had a rigid ROPS removed because of low–clearance operation to have low–profile overturn protection that is automatically deployable. In addition, operators of tractors presently equipped with manually adjustable ROPS, and who operate those tractors with the ROPS in a lowered position during normal open–terrain operation, can be protected.

The results reported here are for a prototype device. The device is not yet marketable. Current plans are to continue developing the AutoROPS as a feature for new tractors, with modifications being based on results of testing in actual field environments. Design modifications may be needed for weather effects, dust and debris effects, maintainability, and human factors encountered in normal operation, so that the AutoROPS can be counted on to provide its protective function when needed. Cost improvements must also be made.

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