INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN
ICED 03 STOCKHOLM, AUGUST 19-21, 2003

THE EVOLVE PROJECT – A MECHATRONIC PROJECT FOR FINAL YEAR STUDENTS.

Johan Andersson and Jan-Ove Palmberg

Abstract

Within this paper results are presented from a large project course in mechatronics given at Linköping University in Sweden. The project was carried out by six master students on the mechanical engineering program with the goal to design an active rear wheel steering system for a passenger car using a hydraulic actuation system and steer-by-wire technology. The system was implemented in a regular Volvo V70 and successfully test driven both at the university and at Volvo Car Corporation. Important issues discussed in the paper include; the successful integration of different engineering domains, design with the help of modern computer aided engineering tools, the importance of working with real hardware and the value of a close connection between education, research and industry.

Keywords: design education, mechatronics, computer aided learning, industrial case study

1 Introduction

This paper presents lessons learned from the first year of the Evolve project. The Evolve project is a co-operation between Linköping University and Volvo Car Corporation that is intended to be running over a period of three years. The overall technical goal with the project is to realize a patent known as the autonomous corner module (ACM) [6]. ACM is a flexible unit (a module) which includes individual steering, damping, propulsion, braking and levelling of each wheel in a vehicle, for example in a passenger car.

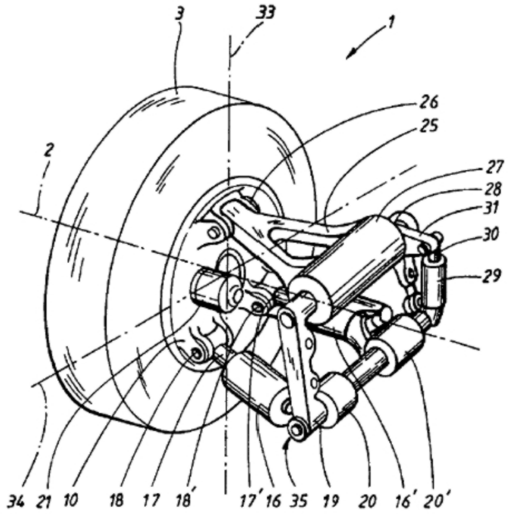

Figure 1. The autonomous corner module patent, after Zetterström [6].

With the ACM concept the characteristic of the suspension of the car can be decided on in the software. This makes it possible to use the same mechanical components on different sizes and types of vehicles. In Figure 1 a schematic sketch of the wheel arrangement is shown. In the figure one can see the actuators controlling the steering angle and the camber angle of the wheel, 16 and 16'. Number 29 is an actuator controlling the pretension of the torsion spring unit, number 27, which acts as both spring and damper.

For the first year of the project the student were assign the task of designing and implementing a steer-by-wire system for the rear wheels on a regular Volvo V70. There were six students, all from the mechanical engineering program, in the project group and the project ran on the spring semester, i.e. from January to June. The aim was to design a system that made it possible to control both steering angle and the camber angle for the rear wheels. The results are reported in references [1] and [5]. The final aim of the Evolve project is to extend the result from the first year to the front wheels and also to include active damping and suspension.

2 Theoretical background

The starting point for this project is that a closer interconnection between education, research and industry will lead to synergies for all parties. A closer connection between research and education leads to better and more interesting education and more innovative results [2]. Furthermore, the industrial involvement gives the students insight into real world engineering projects, and the university the possibility to analyse the problems faced by the industry. From an industry perspective there is of course a transfer of knowledge from the university, but one should not underestimate the value of personal contacts both with the students as conceivable employees, and with the university for future research projects.

The continuation of this paper will follow the ideas presented in the CDIO syllabus [3]. The CDIO syllabus states that: ”Graduating engineers should be able to Conceive – Design – Implement and Operate complex value added engineering systems in a modern team-based environment”. This project deals with exactly these issues.

In this context conceiving involves issues such as identifying market needs, setting requirements, conducting high level or conceptual design and development of project management. Design includes aspects of the actual design process and naturally intensified studies of the different engineering disciplines involved, i.e. mechanics, hydraulics, electronics, control and vehicle dynamics. As these different systems should all be integrated the design process is truly multi-disciplinary as well as multi-objectives.

Implementation embraces the realization of the designed sub systems in hardware as well as software. It also includes development of the process for implementation as well as for testing and verification. In the CDIO syllabus operation includes design and management of operations, support throughout the products life-cycle and end-of-life planning. However, for this first year of the project, operation was limited to test driving the vehicle and evaluating the results.

This project course addresses all the issues mentioned above and the remaining of the paper is organized so that each of the four different phases are discussed in more detail.

3 Conceive

In the first phase, conceive, the overall criteria have to be studied and broken down to the criteria for this first year of the project Thus, the problem is analyzed and the students have set up their own goals, describing what they should achieve within the project. This phase also includes developed of the project management.

3.1 Setting requirement

Perhaps the most vital aspect in the beginning of a project is for everybody involved to get the same picture of the outcome of the project, i.e. to create a common vision that all participants can agree on. Many problems that might occur later in the project arise due to differences in the perception of the goal of the project.

At this stage it was broadly determined what were going to be achieved and how it should be realized in the car. For example, for this first year it was decided that the focus should be on the rear wheels of the car and that hydraulic actuators should be used to control the wheels. Hydraulics was chosen because we were confident that it could supply the forces and the speed necessary. For a production car electrical actuators would be a more preferable choice. However, today there are no electric actuators available that could cope with the speed and forces necessary. Other issues that were discussed include: what functionality should be included, what is the hardware and software going to look like in a broad outline. Furthermore, the functional requirements of the system where set so that it would match the requirements of a modern wheel suspension.

3.2 Project management

The students were encouraged to develop there own way of managing their project. This included determining who shall be the project leader. Other ways of deciding is for one of the senior teachers to determine who shall be the project leader, and perhaps also change project leader as the project evolves. This gives the opportunity for all students to experience the role of project leadership. However all students might not be suitable as project leaders, and as there were eight students in the project, the time as project leader should have been too short.

In the beginning of the project a project plan was developed and a project organization and work procedures were established. The group were divided into sub groups who were assigned different task. For example at the beginning there were a hydraulic design team, a control algorithm team and an electronics team. These subgroups naturally changed over time both in terms of team size and team members both also in terms of task assignment. Each sub-group managed there own work. Progression of the project was followed-up on weekly project meetings. Each week there were several meetings amongst the student and one more formal meeting with the group supervisors. The group of supervisors consisted of PhD students and faculty members. The PhD students were typically experts on the subjects of the different sub-groups, whereas the faculty members acted as project owners and steering committee.

4 Design

The second phase includes the actual design of the system. In this case it includes a mechanical system, i.e. the actual wheel suspension with linkage, bushings and so on. The system also includes an actuation system that creates the motion, which in this case was a hydraulic actuation system. Finally there is also the control system which comprises sensors, electronics, and a computerized control system.

4.1 Design process

During the design of these systems the students have been utilizing modern simulation tools such as Matlab/Simulink for control algorithm development, Adams for analysing the dynamics of the mechanical system and the in house simulation program Hopsan for hydraulic system design. These tools have proven to be very helpful in order to conduct detailed design and to evaluate different concepts. For the regulator design, co-simulation has been performed to simulate the performance of the complete vehicle in order to determine regulator parameters.

4.2 Mechanical design

The mechanical design was partly conducted before the students actually started with the project. This was necessary due to the lead-time of the hardware manufacturing.

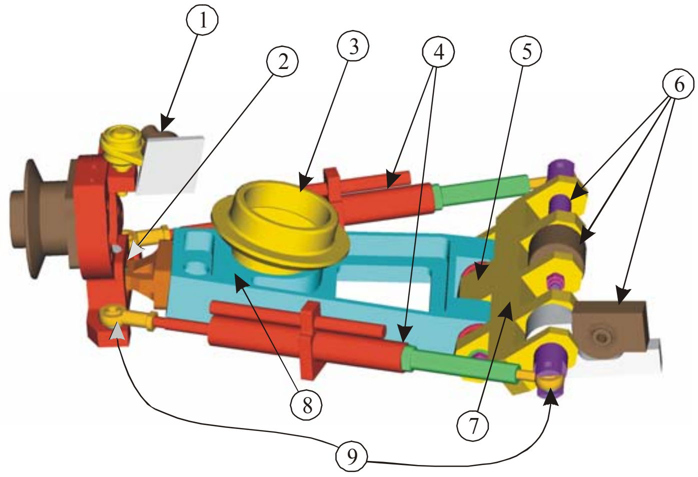

Figure 2. CAD model of the proposed wheel suspension

In Figure 2 a CAD-drawing of the proposed wheel suspension is shown and a photo is shown in Figure 7. The lower part of the suspension has been completely redesigned, to allow steering and change of camber. The proposed concept is such that as much as possible of the ordinary suspension is kept. The upper suspension arm is used in a nearly unmodified shape. Only the connection to the hub carrier has been modified, see nr 1. The existing installation points on the sub frame had to be used, these are pointed out by number 6. Due to the use of the existing sub frame the wheel had to be slightly moved outwards in order to achieve the requested steering angle of 22°.

Two identical hydraulic actuators, nr 4 in Figure 2, are chosen to control the wheel. This means that to change either the steering angle or the camber angle, both actuators have to be avtiviated. In the early stage of the project tests were made on the hydraulic pistons to analyze how the piston would cope with radial loads, which was the intention with the original concept, shown in Figure 1. The loads from for example braking will in this concept result in radial loads on the actuators. The tests showed that the static friction was drastically increased during such load conditions. Therefore a new solution was developed in order to relieve the piston from load in other than axial direction. Thus a knee like hinge arrangement was developed, see numbers 7 and 8 in Figure 2. This knee together with the upper arm takes care of the brake torque and forces, thereby relieving the actuators from these loads. The knee also supports the spring and damper, nr 3. The knee consists of two parts inner, nr 7, and outer knee arm, nr 8. They are connected to each other via a hinge joint, nr 5. The inner arm is also connected with the sub frame via a hinge joint, nr 6. The hub carrier is connected to the knee with a ball joint, nr 2.

4.3 Fluid power system design

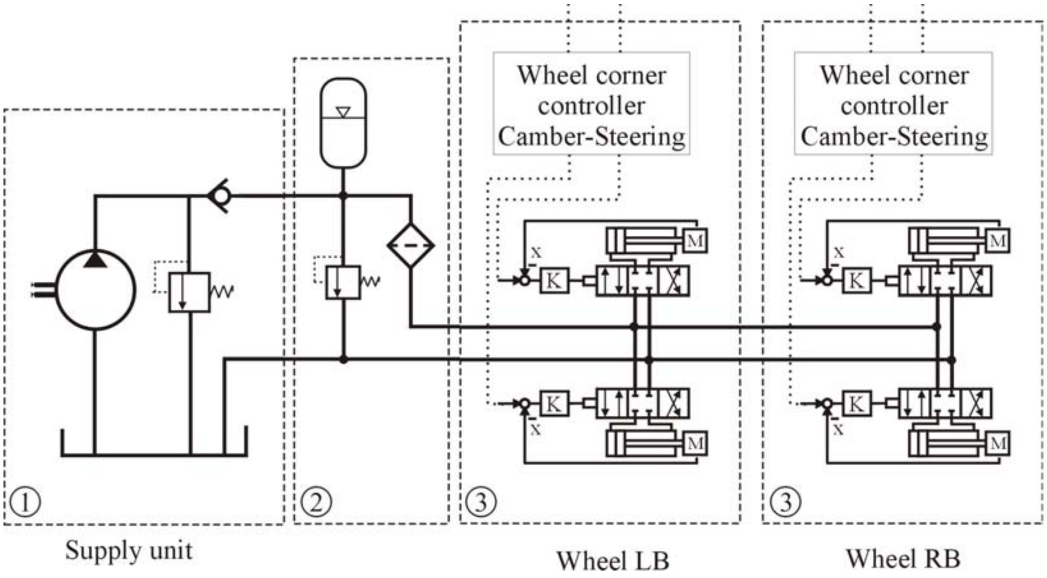

Figure 3. Structure of the hydraulic system.

In Figure 3 the structure of the hydraulic system can be seen. The hydraulic supply system consists of a hydraulic power pack, nr 1, which is an electric motor driven gear pump together with a relief valve and tank built as one unit. In order to keep the pump size down, two accumulators taking care of heavy load cycles are used. The pump is on/off controlled, in order to keep the system pressure within the operational region of the accumulators. There is also an external relief valve which limits the maximum allowed system pressure, and an inline high pressure filter. These components are shown in section nr 2 in Figure 3. Each suspension unit is actuated by two small asymmetrical cylinders, which are controlled by separate proportional flow valves. Sections number 3 in Figure 3 show suspension units for each of the rear wheels. Figure 6 shows the hydraulic power supply and control valves installed in the trunk of the car.

4.4 Control algorithm design

The control and measurement system is designed in the MatLab/Simulink environment, with the help of dSpace which is a real-time interface to Simulink. The Simulink environment facilitates controller design whereas dSpace offers real-time capabilities for simulation, controller testing and controller implementation.

In Figure 4 one way to organize the control system can be found. So far, the main focus has been to be able to position the wheel as desired, i.e. from given steering and camber angles, position the wheel accordingly. This is level 1 in Figure 4, the inner actuator loop. Some work has also been done to level 3, the speed dependent steering control. The strategy implemented here is to steer in opposite direction compared to the front wheels at low speed and in the same direction at high speed. This control strategy allows for good manoeuvrability at low speed and increased stability at high speed. The speed and steering wheel angle are gathered from the vehicle's CAN bus.

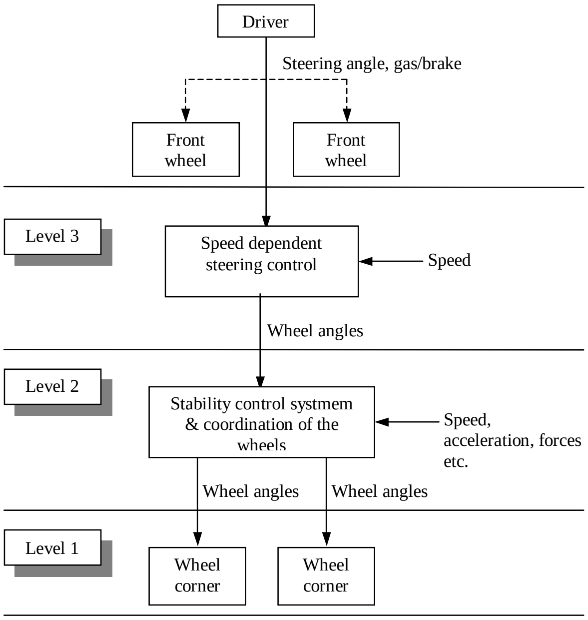

Figure 4. Control system hierarchy.

5 Implementation

In the third phase the students implemented their design in hardware as well as software and integrated the different sub-systems in the test vehicle. This phase included building of hydraulic circuits, development of control electronics, and implementation of control algorithms on the computer in the trunk of the car, see Figure 5. All hardware implementations except of machining of the actual wheel suspension have been conducted by the students. The students divided themselves into two groups, one electronics group and one hydraulic group.

5.1 Sensors and electronics

In order to close the cylinder position loop, each actuator is equipped with a linear position sensor. Furthermore, a position sensor is also attached to each damper. These sensors together with a geometrical description of the suspension make it possible to determine the wheel position and attitude. The geometric description is implemented as look-up table in Matlab/Simulink which have been created by modelling the kinematics in Adams. Nine pressure sensors are also used, one for the system pressure and one for each of the eight cylinder chamber pressures. The pressure sensors located at the cylinder chambers are not needed for the position control and are only included for measurement purposes. They could however be used for control purposes to increase the damping of the system.

Figure 5. The complete system installation in the trunk of the car.

The electronic development included for example; amplifiers for the control signal from dSpace needed in order to the power the control valves, voltage stabilizers that ensure that the pressure transducers are powered with a constant voltage and power control for the hydraulic pump. The control electronics are integrated in the black box to the left in Figure 5.

5.2 Hardware implementation

The major part of the hydraulic system is situated in the trunk of the car, see Figure 6. From the control valves the fluid is directed to the hydraulic pistons first through pipes and closer to the wheel through hoses, see Figure 7. In Figure 7 it is shown what the wheel suspension looks like in the car. It is clear that this arrangement does not meet the robustness requirements of a production car. That is however not the issue in this project.

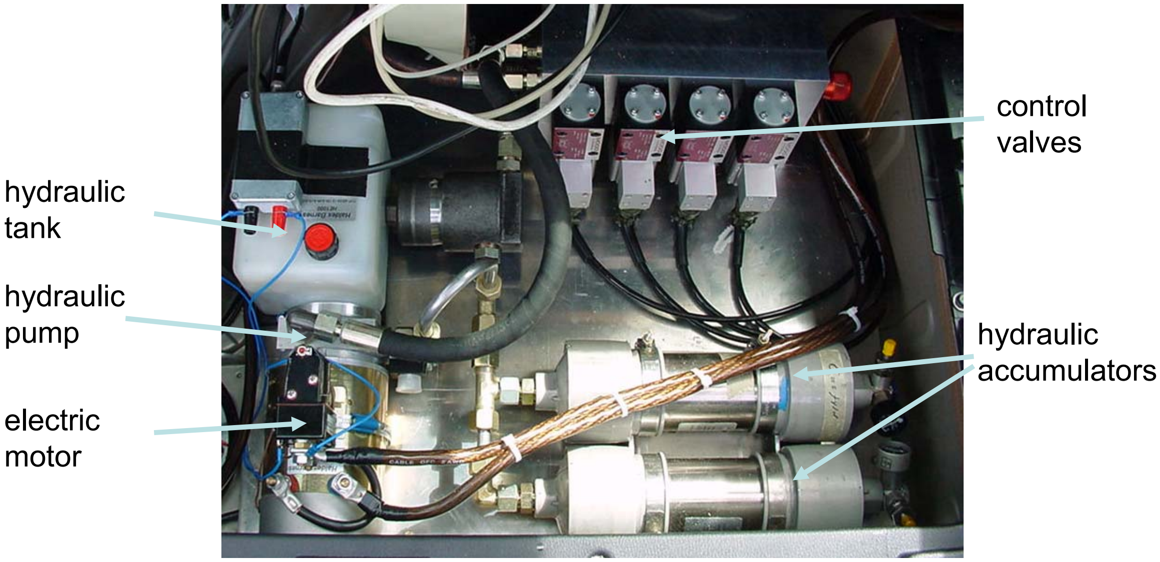

Figure 6. The hydraulic installation in the trunk of the car.

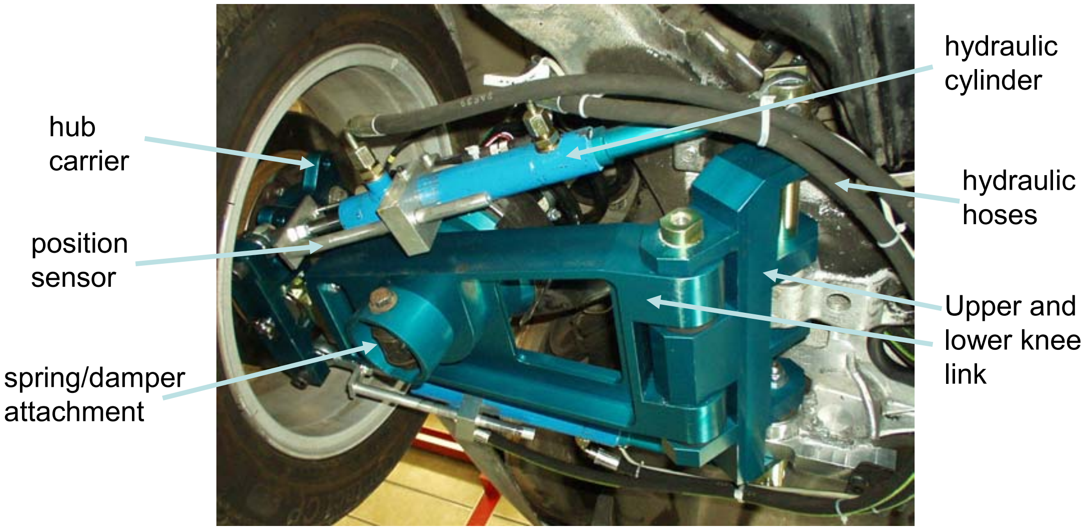

Figure 7. The new wheel suspension seen from bellow.

5.3 Testing and verification loop

Each sub system was tested separately before being implemented in the car. The electronics were first tested, then the communication with the computer. Thereafter one valve was controlled to manoeuvre one hydraulic cylinder in a closed loop system. Once this miniature system was working the complete system were implemented in the car and connected to the CAN bus in order to gather the inputs from the driver. Encouragingly, when everything was connected in the car, the system worked well, already at the first test.

6 Operation – results from the first year

In the final phase the test vehicle has been operated in order to evaluate the system and get feedback on the design. Before actually driving the car the system was tested with the car lifted. Then the car was slowly test driven at the university. The rear wheel steering is speed dependent so that at low speeds the rear wheels steer against the front wheels in order to reduce the turning radius, see Figure 8. Finally the car was driven by Volvos own test drivers at the Volvo plant in Gothenburg, where it also was presented on display for the Volvo engineers. All together the car arose great attention at Volvo.

Furthermore, already in January a date was set for a public demonstration of the car at a national workshop held at the university. Some 30 people from fifteen different companies were invited to attend. At this demonstration the students gave a seminar and a live demonstration of the car.

Figure 8. Reduction of the turning radius with means of active rear wheel steering.

7 Discussion and conclusions

When interviewing the students they stress that the most positive thing was the possibility to work on a project that resulted in something real; not just a document or a piece of laboratory equipment, but real hardware as it is used in industry. Furthermore, the genuine interest shown by the industrial partner experienced very positively as well. Moreover the project gave the opportunity to apply many of the skills learned during the engineering studies on a practical problem that involved both hardware and software systems. The most prominent issues were, design and development of control electronics, design and implementation of fluid power system, modelling and simulation of multi domain systems and practical application of control theory.

However, project management could have been better, mainly regarding communication between the different sub-groups. Today there are no courses in the engineering curriculum where project management is treated and therefore we need to emphasis this for the continuation of the Evolve project. Another issue that has to be improved by the supervisors is to focus more on the non-technical aspects of the project, for example the writing of the report. This year the focus was very much on getting the system to work, to a great deal depending on the complexity of the project and the limited number of students. However, a closer follow-up is needed so that the students are actually writing continuously on the report, that the time table is being updated as the project evolves, and that the project is managed well.

From a university perspective the project has been very successful. The students have carried out a rather complex mechatronic project from the design stage to operation of the complete vehicle. The project has provided valuable engineering knowledge both on a technical level but also in terms of project management, team work and communication. It has been shown that the student can carry through very complex projects if they are just given the right prerequisites. They are capable of handling advanced computer programs in order to solve problems that arise during the progression of the project if they get adequate supervision.

The interaction between the three involved parties, that is, industry, research and education has been very crucial to the success of the project. The close cooperation with industry has made the project more realistic in terms of working with the real hardware (the vehicle), keeping to schedule and meeting the requirements of the project. Furthermore, synergy between research and education leads to better education and more innovative results, where both research and education can benefit, as has also been stated by others [2, 4]. Finally it has been seen that the physical system, in this case the car, could be the common denominator that brings education, research and industry tighter together.

As a result of the Evolve project a Volvo V70 has been rebuilt and is has been test driven at Volvo Car Corporation. During the project the students have designed, build and implemented a novel wheel suspension and finally operated the modified car. As one result the turn radius is decreased by 33% due to the possibility of rear wheel steering. There are however other functionality that could be realized once rear wheel steering is implemented, e.g. stability control, line changing aid, increased wind stability and many more. This is however the task of future projects.

8 Acknowledgments

Volvo Car Corporation has financially supported this project. Furthermore Haldex AB and CA Verken AB have been supplying the project with hydraulic components. This support is gratefully acknowledged. The authors also wish to thank the students, researchers and technicians at the university and the contact persons at Volvo Cars for their efforts that made this project possible.

References

[1] Bagge M. et.al. Evolve – Autonomous corner module part I: Control and implementation of a hydraulic actuation system for steering and camber control of a Volvo V70 T5, Technical report, Division of Fluid and Mechanical Engineering Systems, Department of Mechanical Engineering, Linköping university, Linköping, Sweden, 2002, (In Swedish).

[2] Casar, J., Encouraging students' attitude of innovation in research universities, European journal of engineering education, vol. 25 no.2 pp. 115-121, 2000.

[3] Crowlew E., The CDIO syllabus: A Statement of Goals for Undergraduate Engineering Education, MIT CDIO Report #1, Dept. of Aeronautics and Astronautics, Massachusetts Institute of technology, Cambridge, MA, USA. See also CDIO homepage: www.cdio.org

[4] Oehme F. and Seitzer D., Learning by doing: how to include new requirement of research in engineering education, European journal of engineering education, vol. 25 no.2 pp. 131-137, 2000.

[5] Zachrison A., Rösth M., Andersson J. Werndin R., Evolve – A Vehicle Based Test Platform for Active Rear Axle Camber and Steering Control, in Proceedings of SAE World Congress, Detroit, USA, March 3-6 2003

[6] Zetterström S., Vehicle wheel suspension arrangement, Patent No. WO0038939, US-patent No. 0030400.

For further information please contact:

Johan Andersson
Dept. of Mech. Engineering, Linköping University, 581 83 Linköping, Sweden, Phone: +46 13 281711 Fax: +46 13 130414, E-mail: johan@ikp.liu.se, http://hydra.ikp.liu.se/~johan/.