FLUDICON
FLUID DIGITAL CONTROL

INDUSTRIAL APPLICATIONS OF ERF-TECHNOLOGY

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To demonstrate the industrial application and benefits of the ERF-technology, FLUDICON (Fluid Digital Control), a recent spin-off of the DÜRR-Schenck group initiated a project with the working title "Adaptronic Transport Systems with electrorheological fluids (ERFs) for the transport of sensitive goods". This project was successfully completed and resulted in a fully functional ERF-hydraulic transporter system. The general system design including the specific ERF-actuators with integrated ring-segment ER-valves is discussed. Parallel to fully active systems, research work is being carried out on ERF-damper design for commercial automobiles and on the development of an ERF-servovalve.

1 Introduction

Since the development of RheOil – a new ER-fluid – which is non-abrasive and can be used in combination with standard hydraulic components, FLUDICON has concentrated its efforts to bring this technology out of the laboratories and into the industry. The high dynamic response of RheOil, its ability to be progressively adjusted and the simple design of effective ER-valves allowing for large pressure drop spread are three key features which need to be implemented when exploiting the industrial benefits of this technology. The sum of the key features of the ERF technology is the additional functionality which allows innovative solutions to problems which cannot be solved with "classical" technologies. To demonstrate this additional functionality, customers must be given not only an ERF application which encompasses the key features, but a complete system consisting of fluid, mechanical application, high voltage controllers, sensoring and the control system/algorithms which, working as a unit, make this functionality available. FLUDICON has all of these capabilities.

2 The Adaptronic Transport System (ADT)

During the long-distance road haulage of goods, the cargo will be exposed to an everchanging array of road surface and motion dynamics, with changes and fluctuations coming quickly and not always in any easily predictable pattern. Given these variables, the road transport of sensitive goods has always carried an element of risk. Sensitive cargo would fare better floating in its own buffer zone, protected from potential vibration or motion damage.

Fig. 1: The ADT-System is ideal for sensitive cargo

FLUDICON GmbH, a recent spin-off of the Dürr-Schenck group, has developed a system for the safer transport of sensitive goods, the adaptronic transport system (ADT). (Figure [1] shows the ADT.)

The ADT system is based on the properties of the new electrorheological fluid RheOil which can alter its viscosity instantly and reversibly in an electric field. Using RheOil, a hydraulic system mounted on the loading area of a truck uncouples sensitive goods from road unevenness and aligns the forces resulting from motion dynamics, such as cornering or acceleration, orthogonal to the load surface. The transported goods lean into the curve, for example, while at the same time floating, free of shock or vibrations, over the road (the skyhook principle).

FLUDICON has realised this goal via three hydraulic cylinders, which carry the base load, and three ERF-cylinders (RheAct), which compensate for road bumps and the forces resulting from motion dynamics. All cylinders are mounted between the vehicle chassis and the platform which carries the sensitive load. The ADT system is powered by standard vehicle hydraulics. The sensor array is a modern combination of displacement, force and position sensors (including laser fibre-optical gyro and magnetostriction) with their data processed via self-developed electronic hardware to control signals for the RheActs. The response time of the system is in the millisecond range, so that the vehicle really does seem to move freely underneath the floating load.

This new ADT system can find application in the transport of injured people or sensitive goods and also in shipping and military domains. In general, active vibration control is considered the objective of this application. The system developed by FLUDICON has passed all relevant functional tests and will now help provide innovative solutions in various applications.

3 RheAct cylinders

The ERF-cylinders (RheAct) at the heart of the ADT system have been designed as double-acting, single-rod actuators with integrated ER-valves (RheValve). The four RheValves are arranged as a full hydraulic bridge, allowing for maximum control possibilities. To minimize the RheAct dimensions and improve their hydraulic stiffness, the RheValves were arranged as four electrically and hydraulically isolated positive electrode ring segments inserted between cylinder wall and outer casing. A schematic representation of the arrangement and a close-up view of the cylinder is given in figure [2].

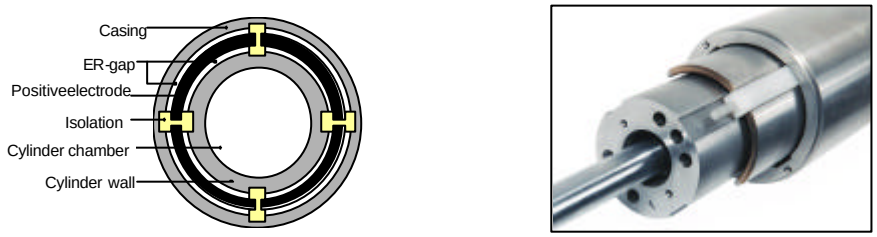

Fig. 2: RheValve arrangement (schematic and realized)

The RheAct range of dynamic cylinders also includes double-acting, double-rod actuators with integrated RheValves.

These RheActs from FLUDICON can be implemented in all applications where high dynamics and frequencies in combination with the power density of hydraulic systems is required. The first application presently being tested is an elastomer testing machine for frequencies in excess of 1000Hz. Open loop control has been achieved beyond this value. The next step is to realise control hardware which will allow closed loop control up to this frequency. To this effect, a 10kHz loop update rate is a minimum requirement.

4 RheDamp vibration damper

One of the applications which can enormously benefit from the added functionality of the new ER-fluid RheOil form FLUDICON is the automotive shock absorber/damper. The patented ERF-damper RheDamp from FLUDICON is a modified automotive monotube shock absorber which makes use of a single spiral channel as an ER-valve, eliminating the need for a complicated plunger valve. Figure [3] shows a cutaway section of the shock absorber. The positive electrode in the plunger is separated from the tube wall by a spiral plastic strip. This strip provides the necessary guidance, maintains the correct ER gap (1mm) and artificially increases the length of the ER valve. With a straight RheValve, the plunger would have been three times the length – drastically restricting the available stroke. The positive electrode in the plunger is isolated from the rod by a thermally stable plastic and the shielded control cable led through the hollow rod for connection to the control unit mounted in the vehicle.

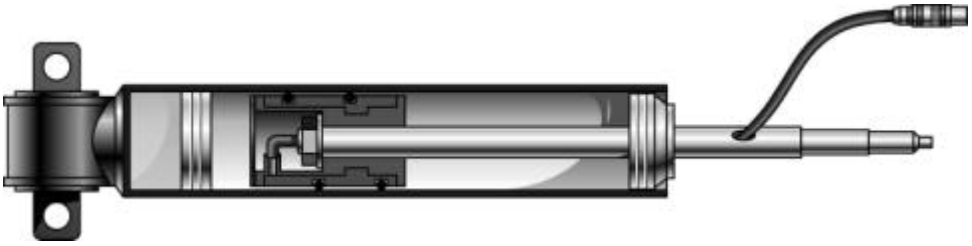

Fig. 3: Section through RheDamp shock absorber

Tests have confirmed the adjustable damping characteristics and an open-loop system response time of 6ms has been determined.

The damping characteristics of RheDamp have been integrated into a complete vehicle simulation system and a suitable control algorithm designed and implemented. A simulation of the vehicle undergoing a double lane change at 100km/h on an uneven road was enacted without and then with the RheDamp. Figure [4] shows two still frames of the simulation. The film of the simulation impressively demonstrates the potential which such a continuously variable shock absorber offers with regard to comfort and safety.

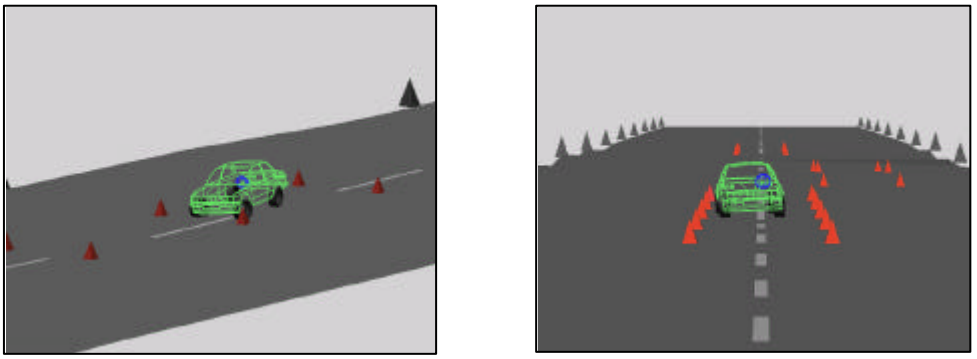

Fig. 4: Simulation results of vehicle without and with RheDamp shock absorber

5 RheCon ER controller

To realize the benefits of the ERF technology regarding improved control conditions, it is necessary to have a high voltage supply unit which fulfills the following criteria:

- Highly dynamic field generation and discharge
- Stable field control independent of load
- High efficiency
- Output voltage 0- 6kV
- Sufficient output current

Having been unable to acquire a suitable unit externally, FLUDICON has developed an ERF controller, RheCon, which fulfills all these criteria. With rise and fall times of 0.3ms, the true dynamic response of RheOil and all other ER-Fluids can now be enhanced. Accurate modulation of the unit can be realised up to 1000Hz for a sine wave with an amplitude of 6kV. The load independent stability allows for correspondingly higher frequencies at lower amplitudes (e.g. 1500Hz modulation at 4kV output voltage amplitude). Figure [5] shows the RheCon controller as a stand-alone unit.

Figure 5: RheCon, a highly dynamic ER controller

Taking the needs of the ER fluid research community into consideration, this unit is also equipped with an accurate load current sensor, flashover monitoring and further features. Compliancy with CE norms ensures that all necessary safety standards have been adhered to. The unit can be used in conjunction with industrial applications and/or rheological testing equipment. For more information on this controller, please see the paper "Electronics and mechanics – a balance act in ERF applications".

6 RheValve ER servovalve

Given the available shear stresses of modern ER fluids (~ 8000Pa at 5.5kV/mm and 20000s^{-1} shear rate) with a moderate zero field viscosity of 30mPas, application dimensions can be quickly estimated using a simple Bingham model. Despite calculation inaccuracies, the feasibility of an ERF solution for a specific application can be deduced. Where application size is critical, given a desired on-off ratio, it is sometimes the case that no presently available fluids possess the necessary shear strength under electric field to allow for the implementation of a direct ER gap valve.

To overcome this problem, FLUDICON has developed an ER servovalve: RheValve. RheValve combines the advantages of classical servohydraulics (large gain from a small signal) with those of RheOil (adaptive control). Figure [6] shows a cutaway CAD model of this new RheValve.

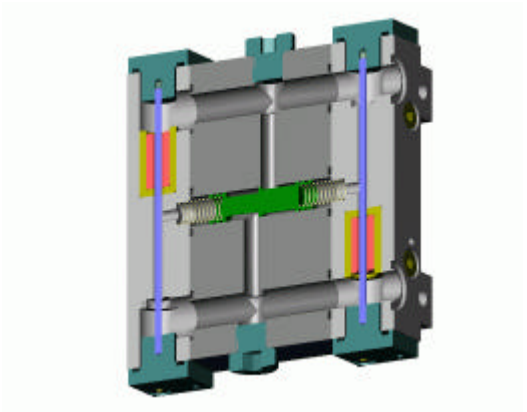

Fig. 6: RheValve servovalve (cutaway CAD model)

Given control channels with ER gaps of approximately 0.5mm, a servohydraulic pressure gain of factor eight can be achieved at volume flows in excess of 50litre/min. – a realistic value for standard hydraulic applications.

By activating RheOil in the control channel only, a reduction in the required voltage by factor two can be achieved. This brings enormous advantages with regard to the size of RheCon and also the required power consumption.

Tests of RheValve in combination with RheDamp will be carried out this year in collaboration with an industrial partner.

7 Industrial applications

A successful transfer of ERF benefits into commercial applications requires the joint effort of ERF specialists and industrial partners. Given the advanced state of prototype applications as discussed above, the industry is starting to take a new look at the ERF technology with regard to their own products. For the customer-specific development of industrial applications, FLUDICON offers an innovative and complete range of necessary components: RheOil (ER-fluid), RheCon (ER-high-voltage amplifier), RheValve (fast response ER-valve), RheAct (highly dynamic ER-actuator) and RheDamp (smart ERdamper).
Examples include rotational dampers, combined gas-spring and damper units and automotive shock absorbers as well as the testing machine mentioned in chapter 3.

Based on these components and the total competency in the development of ERF products – that is in fluid-know-how, engineering, controls and testing, FLUDICON develops a range of customer-specific fluid mechatronic applications. Along with the ADT system active vibration damping systems, fast actuators, highly dynamic valves and force-feedback-systems are being developed and investigated for customers from various industries such as machinery, medical, automotive and commercial vehicles.

8 Summary

An industrially viable ER fluid like RheOil, combined with competence in mechanical hardware, electronic controllers and control methods has allowed FLUDICON to successfully demonstrate the ability of the ERF technology to solve real-world problems. This success has given customers the confidence to integrate ERF technology from FLUDICON into their products.

From a mechanical hardware point of view, focus is now being placed on actuator optimization, servovalve technology and the improvement of damping characteristics for various shock absorber applications.

The newest ERF controller RheCon from FLUDICON covers all requirements regarding energy, signal form, dynamics and load current feedback for a whole range of applications, so that the selective miniaturization for specific applications can be realized.

To ensure the commercial feasibility of development projects in the pipelines of partners, focus must now be placed on the improvement of RheOil regarding sedimentation stability, temperature range and on-off shear stress gain.

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