Piston Accumulator with Detent Function for Automatic Gearboxes

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Abstract

This paper presents a new developed spring tensioned piston accumulator with detent function. A relatively light, small and cost-saving solution for storing hydraulic energy and activating it by means of a holding magnet, the component is applied particularly for the assistance of start-stop-systems in automatic gearboxes. Following an introduction to the principle of operation, the variety of simulation methods used during development are presented. Design and fabrication of key functional parts under the conditions of mass production are described. The article gives an overview on newly developed assembly processes, laboratory testing and experiences since the start of production.

KEYWORDS: piston accumulator, detent function, holding-magnet

1. Introduction

Development of techniques for reducing energy consumption has been a major field of interest throughout the automotive industry for the last years. Long term strategies are for instance electrical drives or fuel cell drive units. However, these solutions have been used on a prototype scale or on small series only, mainly due to costs being still very high.

As a consequence, more evolutionary solutions for reducing and minimizing the fuel consumption of the combustion engine presently are the key point in the aim of meeting the continuously lowering CO2 regulations. In addition to improvements in the engine, the use of a start-stop-system provides a means to further reduce fuel consumption by typically 5% and up to 8 % during city driving cycles. When combined with automatic gearboxes, reaction time after a red light stop is of particular importance. The engine driven gear box pump needs a certain time to build up pressure within the gearbox hydraulic system. During this period, the system is not able to switch a gear and initiate movement of the car. For this reason, numerous car manufacturers offered their first start-stop-systems only in combination with manual transmissions.

An already applied solution to increase pressure build up in the hydraulic cycle of automatic gearboxes is the additional use of a special power pack, which is only used for the immediate pressure build-up within the start phase. However, this principle bears several disadvantages such as relatively high costs, additional weight, large space requirements, the current consumption of the power pack, additional control algorithms to implement the additional electric pump and a decrease of the gearbox efficiency /1/, /2/.

Developmental work on the piston accumulator presented in this paper has been aimed at addressing drawbacks present in existing systems, with a main focus on reducing production costs of start-stop-systems for automatic gearboxes and supporting the introduction of this CO_2-reduction method on a wide range of car types.

2. Principle of work

The component functions as a spring tensioned piston accumulator, with the accumulator containing 2 volumes sealed against each other as shown in **Figure 1**.

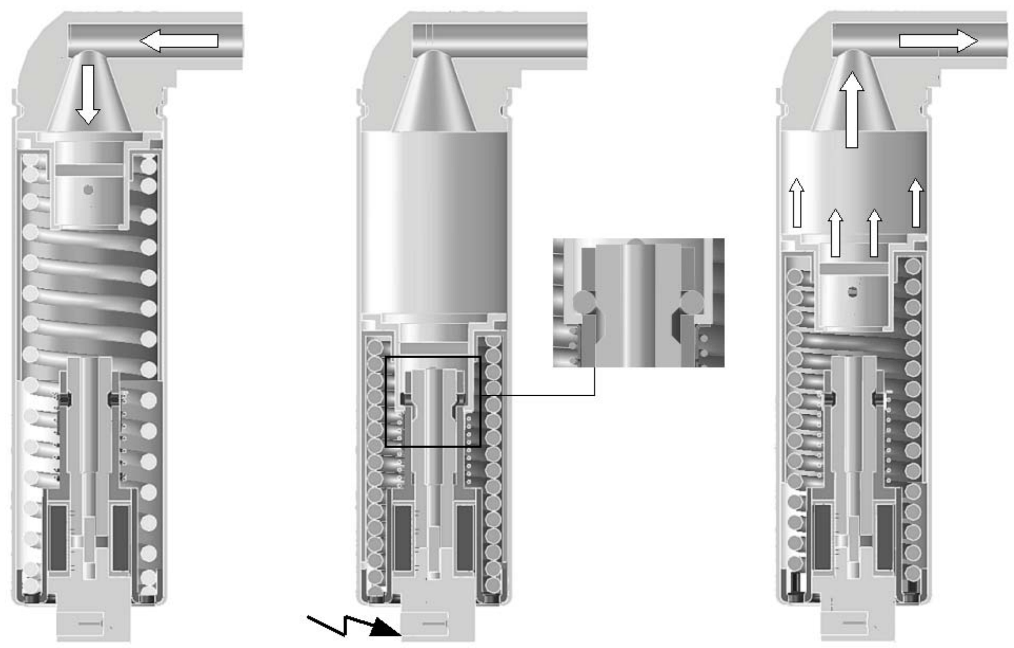

Figure 1: Piston positions and movements in typical situations

The pressure chamber is connected to the pressure line of the hydraulic system. Without hydraulic pressure, the piston is pushed to the first end stop by the pretension of the compression spring. The hydraulic working pressure of typically 10 bars pushes the piston against the spring force to the second end stop, where the volume of the pressure chamber is at its maximum. A detent function enables the component to remain in a position close to this position when the engine is shut off and the supply pressure decreases. Switching of a holding magnet activates the locking. In the start situation, the holding-magnet will be deactivated. The locking elements remove and the compression spring builds up pressure in the oil volume of roughly 100 millilitres, pushing it into the hydraulic system. This process takes place in parallel to the start of the car engine and enables the gearbox control to switch a gear.

3. Simulation-based functional developement

3.1. Holding-magnet

A 2D magnetic field simulation was used for dimensioning and optimisation of the holding-magnet. **Figure 2** shows a half-section of the magnetic circuit with typical distribution of the magnetic flux densities and magnetic flux lines.

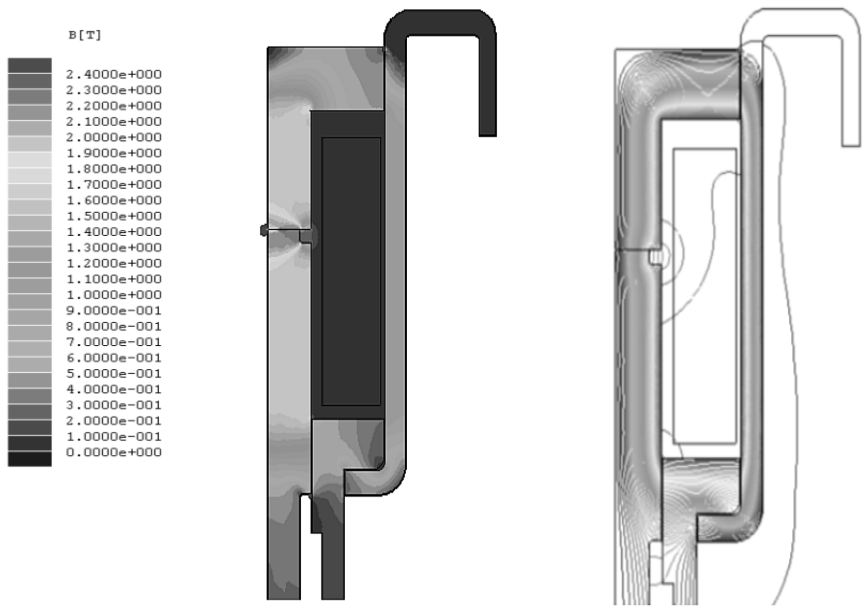

Figure 2: Simulation of the holding-magnet

Securing high holding forces with low current demand was a main emphasis of the work. This was optimised by creating a diameter reduction in the pole region of the armature in order to increase flux density between the moving parts while loosing only a minimum of total magnetic flux. In addition, securing a drop-out current, which has a relatively high minimum value to realise fast activation times, was essential. A cost saving solution without additional part was to add a small ring with typically 0,1mm height and less than 10 % total cross section on the pole area of the magnetic core.

3.2. Component function

A system model of the component covers all relevant functional parts of the piston accumulator and the hydraulic and electric intersections, as shown in **Figure 3**. The coil of the holding magnet is connected to the switch with a suppressor diode to simulate realistic current decrease in the activation phase. On the mechanical side all springs and masses are covered by the model. Special emphasis was put on good modelling of the locking system. The hydraulic part of the model includes volumes and orifices in the accumulator, as well as system pressure and flow restrictions in the hydraulic system for filling and activation events.

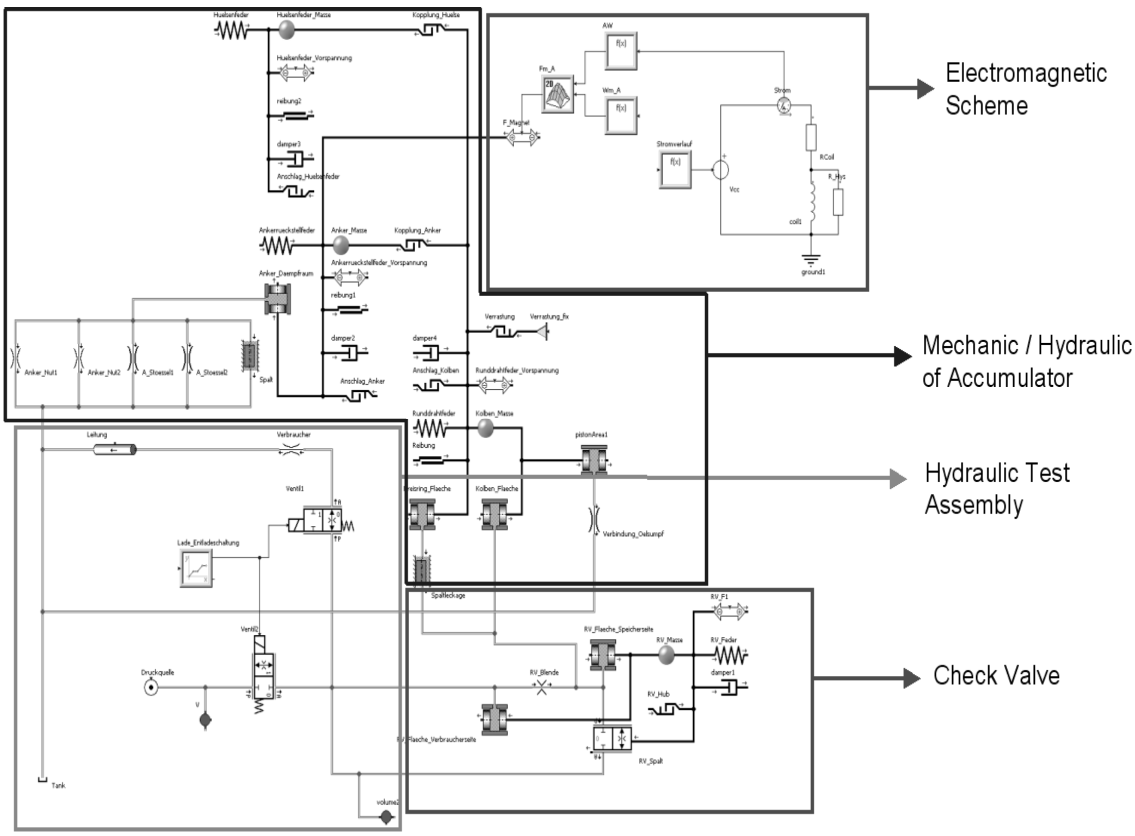

Figure 3: System simulation model of the component

This mathematic model assisted in improving understanding of the interaction of all the parts in the accumulator, optimising their work and investigating the influence of tolerances. A typical result of simulation shows the pressure changes in the accumulator. Filling starts after the force which is build up by the supply pressure is higher than the sum of spring and friction forces. During filling the pressure rises according to the increasing spring force, **Figure 4**. Filling time depends mainly on pressure head and flow resistance at the inlet. A pressure peak indicates the second end stop. Now the holding magnet activates the detent function. When supply pressure is cut off, the pressure in the chamber decreases to zero and the piston moves back some millimetres to the locked position. After electrical switch-off, the coil-current begins to decrease. Due to the suppressor diode it takes some milliseconds till the drop out current of the holding magnet is reached. A peak shows the activation time. From this point spring force builds up pressure and pushes the oil to the system. Without a throttle at the outlet the whole 100ml of oil are delivered within less than 300ms.

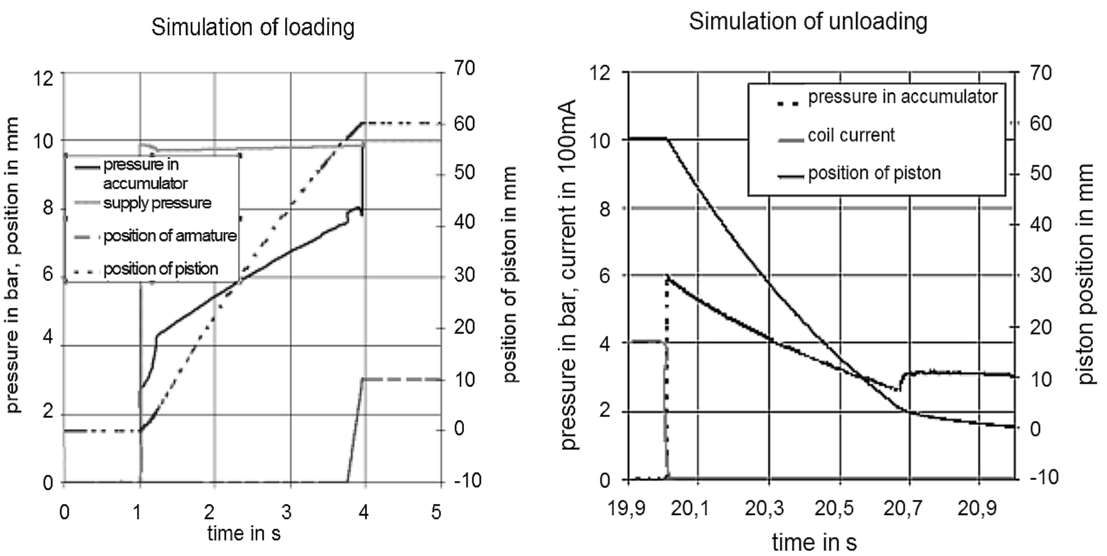

Figure 4: Typical loading and unloading cycle – simulation results

Intense simulation work supported the design of a damping device for the magnetic armature as well as the dimensioning of a dirt sieve, which was added for protecting the volume around the holding magnet from dirt. This volume expands as the spring pushes the piston to the unloaded end stop. Mainly owing to the high viscosity of cold oil, the pressure drop of the sieve has to be prevented from creating a vacuum in the accumulator volume, which would notably increase the activation time. The simulation model enabled us to find a satisfying compromise.

3.3. Vibration

The accumulator is mounted to the gearbox with a braket which is dot welded to the outside of the tube. Due to very small space in combination with tough loads it took some optimisation loops till all vibration tests were passed by the assembly. Static and dynamic 3D FEM simulation showed the successful steps of improvement, **Figure 5**. By tuning the structure an increase of eigenfrequencies was realised. Lower requirements at higher frequencies helped to ensure the robustness of the component.

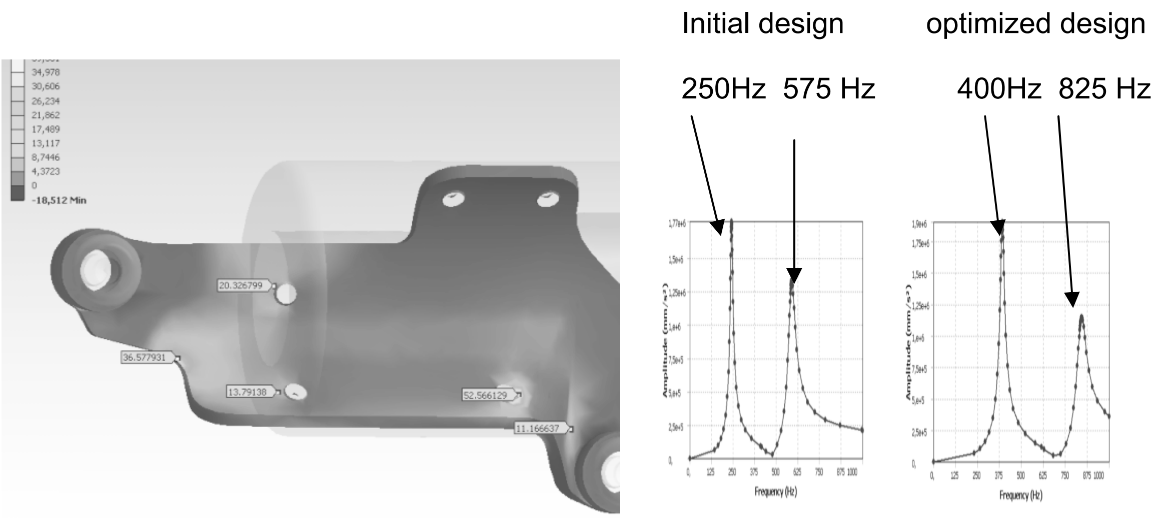

Figure 5: Increase of eigenfrequencies from simulation

3.4. Technical data

An overview on the main technical data realised is given in **Table 1**.

Piston accumulator technical data	
Length	190 mm
Diameter	50 mm
Weight	1150 g
Oil volume	100 ml
Typical pressure	7 bar
Typical filling time	3 s
Activation time	< 30 ms
Energy consumption	5 W

Table 1: Technical data overview

4. Design and production of single parts

A cross section of the accumulator is shown in **Figure 6**. During development, major emphasis was put on finding cost-minimizing solutions for the production of individual parts and assembly. As production numbers are expected to be high, multiple solutions for facilitating off-tool-assembly of as many parts as possible have been developed /3/. A range of the key solutions is presented in this chapter.

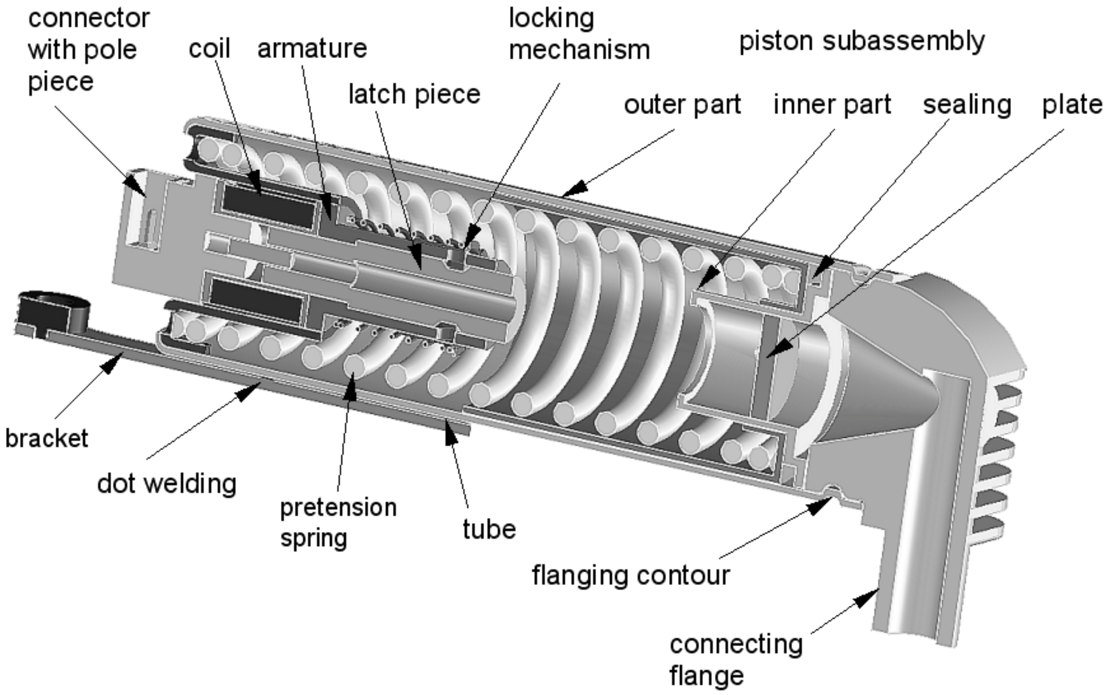

Figure 6: Cross section with key parts

4.1. Piston

The piston is realised as a subassembly. The outside piston cylinder is produced by deep-drawing from a metal sheet with an ambitious highly accurate inside section used to press in the second inner piston part. This cylinder with flange shape is also produced in a deep-drawing process, but from a special hardenable steel. After hardening, only the critical edge, which is in contact with the locking balls is finished by fine turning. A stamped plate is pressed into the inner diameter of the inner piston part to an adjustable position. This piston solution provides the locking region with the required hardness and tolerances, whereas all other dimensions are ready after the deep-drawing and stamping processes of the metal parts. On the outer diameter, the piston sealing system is assembled between inner and outer part before pressing the piston parts. No stretching of the rubber and especially the PTFE sliding ring is needed.

4.2. Connecting flange

Instead of typically used die cast aluminium parts, a solution with high temperature plastics has been developed. During operation, very high loads are caused by vibrations, pressures and extreme temperatures in combination with gearbox oil. As a consequence, several optimisation loops were undertaken until all requirements were met. For reaching a satisfactory compromise between durability in use and securing of a robust process-save production, simulation work and computer tomography were utilised.

4.3. Pretension spring

The pretension spring is a main driver of the overall dimensions of the whole component, bearing high forces of up to 1200N and the large stroke. A special high strength wire was chosen to wind the compression spring. Further improvement of the strength of this part is accomplished by additional heat treatment.

4.4. Overview on further parts

Most other parts are realised by high volume tooling technologies, such as plastic moulding, stamping, bending, deep drawing and sintering. Turning processes are used exclusively around the locking mechanism. The latch piece is made from hardened steel and is pressed on the magnetic armature, which switches the latch between its end positions. This solution provides a combination of hardness and good magnetic properties at the points where they are needed.

5. Assembly and end of line testing

Automated assembly and testing processes in later series production have been a priority topic from the beginning of work. Furthermore, new and critical processes were developed and tested in early phases, with the results frequently having a direct impact on the design of single parts. In the following chapter, a range of examples are presented.

5.1. Welding of pipe and braket

With the high vibration loads rendering a strong design indispensible, mounting of the piston accumulator to the gearbox within limited space was a challenging task. The optimised solution is to directly weld the braket to the outer diameter of the accumulator tube. As the piston with its sealing is moving in the inner diameter, no change of the inner diameter of the pipe can be permitted. Pulse welding was found to be the best technology for this assembly, providing robust process parameters and ensuring high strength and no change of the inner diameter.

5.2. Flanging of the connecting flange and the tube

The outer tube is cut off from a high precision pipe. The closing of the accumulator and a strong mounting method between connecting flange and tube are realised by a flanging process. This assembly has to secure a high plastic deformation of the outside metal tube. On the inside, in contrast, damage of the connecting flange made from plastics has to be prevented. This process development was supported by a variety of nonlinear coupled FEM simulations. The calculations included all the contact topics between flanging tool, tube, sealing ring and connecting flange. Nonlinear material models are used for tube, sealing ring and connecting flange. As a result of this activity, the stresses and strains in the connecting flange were reduced drastically by changes in the shape of the tool and the ring groove, as depicted in **Figure 7.**

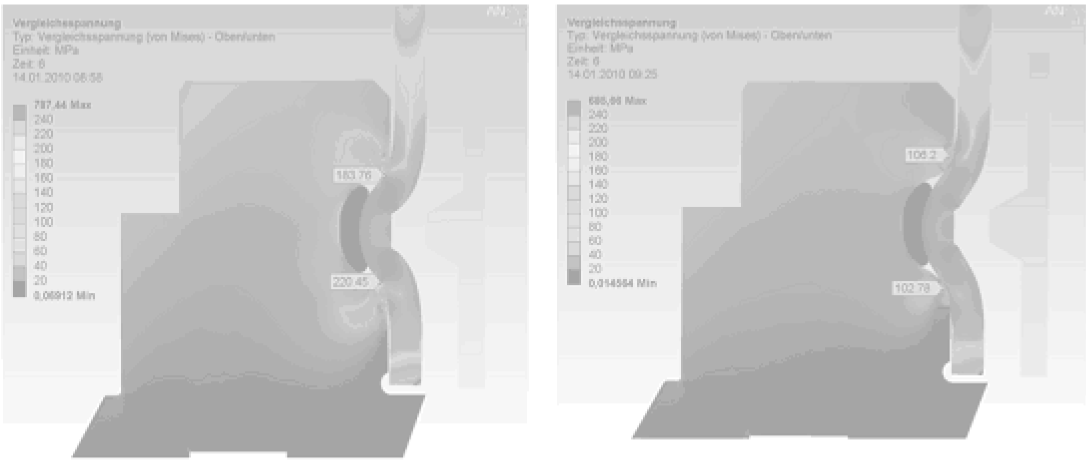

Figure 7: Optimisation of flanging process in simulation

5.3. Blocking element: balls

Six hardened balls are used as blocking elements in the accumulator. An exact number of six balls, placed as blocking elements in the correct positions, is indispensible for ensuring detent function.

5.4. End of line testing

At the end of the assembly line, each piston accumulator has to pass a complex functional test. After flushing and bleeding, different criteria such as switching current, drop out current etc., are examinated. A complete cycle, including loading the pressure chamber, switching the holding magnet, locking the piston and releasing the stored oil back to the system, is fulfilled. Detailed values for filling time, activation time, pressure build up etc. are calculated and compared with the limits. This testing process occurs in a complex test rig with 3 cavities, where the accumulators are tested in parallel.

6. Validation

In order to ensure a good basis for further testing in the gearbox and in the car, function and life cycle were evaluated intensively on component level in the laboratory.

6.1. General function in temperature range

One of the main requirements is the temperature range between -30°C and +150°C within which the piston accumulator has to work. Therefore, special test rigs had to be build for this project. Powerful heating and cooling devices feed two separate test rigs for functional and endurance testing with well tempered oil. During functional testing, a major effort was put into checking and optimising the component's performance within a wide range of boundary conditions of temperature, pressure and throttle size at inlet and outlet. The complete matrix to be tested before and after endurance test program included more than hundred different test conditions. A challenging task within this work was the optimisation of the piston sealing system in terms of fulfilling specified limits under all conditions.

6.2. Life cycle testing

A typical validation program consists of a row of different tests, including thermal shock tests in oil and air used as time-lapse test for aging, vibration and shock testing and a functional endurance run with different operating temperatures. The complete procedure took up to six months per type of accumulator.

7. Series launch

Series production started in 2010 with relatively low volumes. Meanwhile some hundreds of thousands of piston accumulators have been produced and delivered. The product shows robust function in daily use. So far no failures where found on the car.

In parallel to the already running projects, a multitude of decisions to use the start-stop function with piston accumulator have already been made and will contribute to a significant rise in production numbers during the next months.

8. References

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