Innovative Duplex Filter for Hydraulic Applications

Klaus Mössinger

ARGO-HYTOS GmbH, Industriestraße 9, 76703 Kraichtal, E-mail: k.moessinger@argo-hytos.com

Abstract – Innovative Duplex Filter for Industrial Applications

For decades, duplex filters have been put to use virtually unmodified. Technologies, handling and use of materials show enormous potential for improvement. Filter element removal/replacement is performed according to a complex process sequence.

With the newly developed Duplex Filter, the market demands concerning simple filter element removal/replacement, as well as weight and pressure loss reduction are fully met.

KEYWORDS: Duplex filter, weight and pressure loss reduction, fully automatic change-over process, automatic ventilation, industrial applications

1. Introduction

Duplex filters are filtration systems in which two filter elements are installed, yet the hydraulic medium flows through only one of the elements at any one time. The second element is inactive. As soon as the permitted pressure loss of the first element is reached due to particle build-up, the operator changes over without interruption from the dirty to the new, clean filter element. This ensures continuous operation of the system without interruptions or downtime.

2. State of the Art

Filter element removal is performed in accordance with a complex process sequence (**Figure 1**), which involves substantial operational risks. For instance, vent and pressure compensating valves need to be opened and closed before and after the change-over process in order for the change-over lever to be moved and the serviced filter bowl to be filled again.

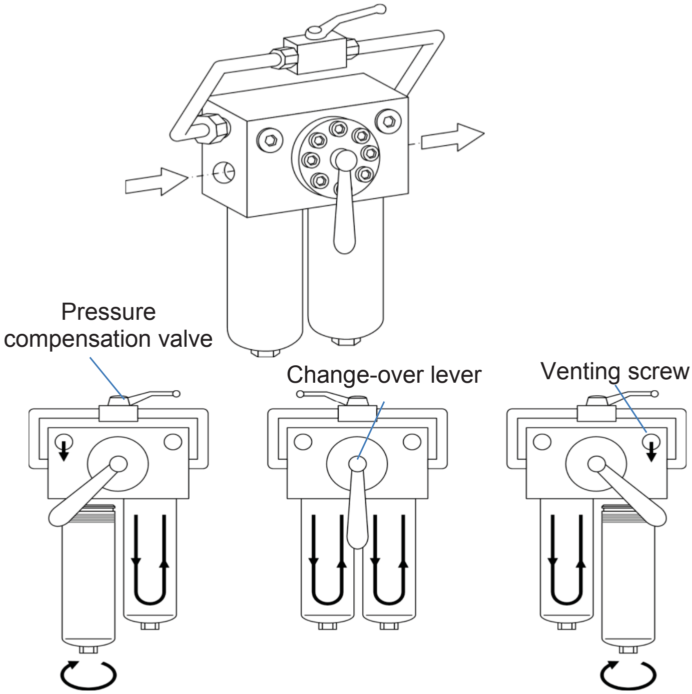


Figure 1: Existing Duplex Filters

3. A New Approach

With the help of modern software tools, such as FEM and CFD, a completely novel housing and change-over concept could be realized.

Figure 2: Newly Developed Duplex Filter

3.1. New Change-Over Concept

The objective in creating a new change-over concept was to reduce the change-over process to a single operational step, which automatically includes and performs the functions:

- pressure compensation,
- ventilation and
- filling of the serviced filter bowl.

The entire process sequence should be characterized by maximum safety and absolutely fool-proof execution.

3.1.1. Change-Over Sleeve

The change-over sleeve (**Figure 3**) can be described as the central part of the new change-over technology. It separates the pre-filtration side from the filtered side and controls the flow between the two filter bowls. The high transmission ratio (**Figure 4**) between change-over lever and change-over sleeve allows for low change-over forces; the operator can move the lever quite effortlessly.

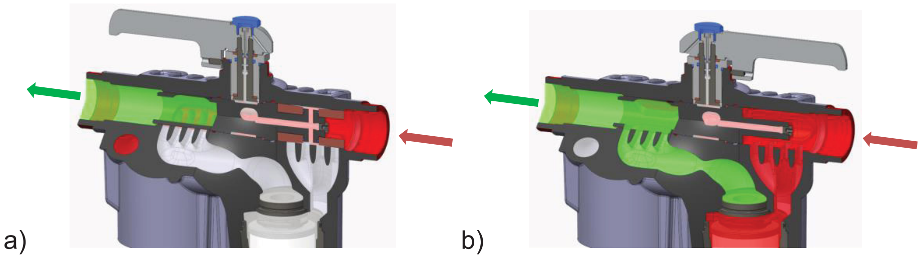


Figure 3: Change-Over Sleeve. a) Right filter housing closed, b) Right filter housing opened.

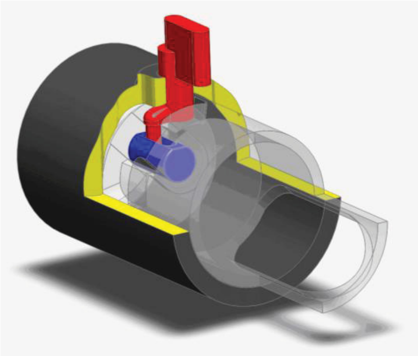


Figure 4: Change-Over Mechanism

3.1.2. Pressure Compensation during Change-Over Process

Once the change-over process starts the pressure compensation valve (**Figure 5**) is opened, without causing the change-over sleeve to move. This leads to immediate pressure compensation between the inner and outer side of the sealing areas at the change-over sleeve.

The change-over lever (Figure 5) can be rotated by 20° without any twisting of the change-over sleeve.

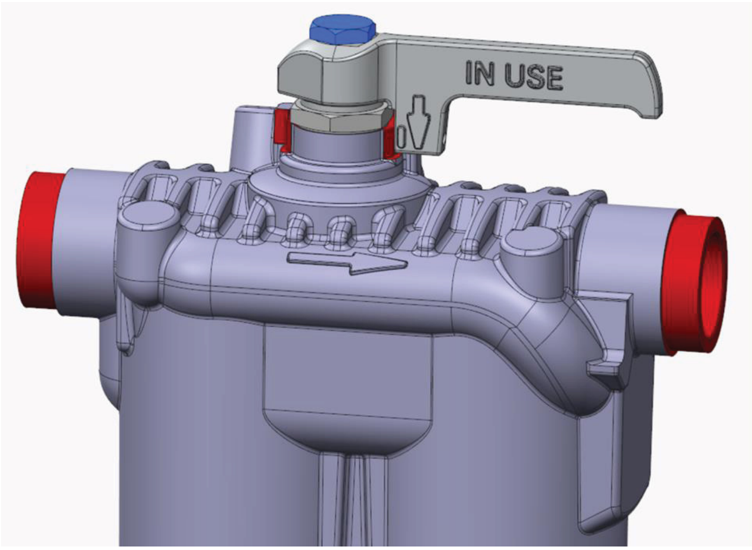


Figure 5: Duplex Filter Change-Over Lever

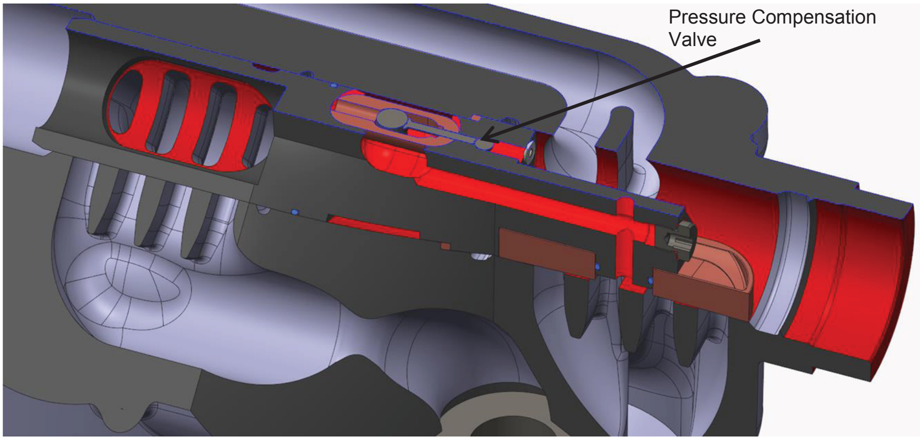


Figure 6: Automatic Pressure Compensation

3.1.3. Automatic Ventilation System

Aeration

Once the draining screw is opened or the filter bowl is removed, the drained oil opens the vent valve (**Figure 7**) and the system is aerated.

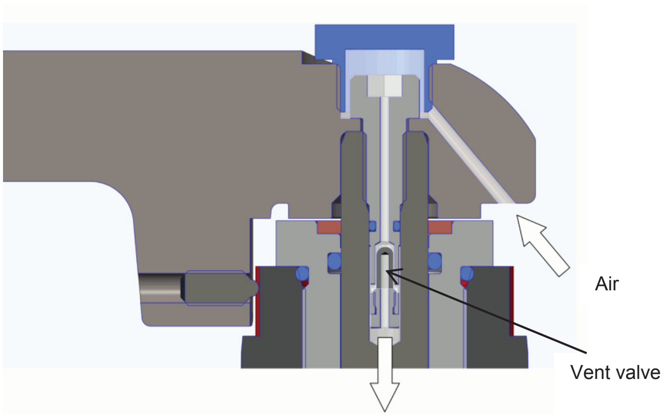


Figure 7: Automatic Aeration

Ventilation

Once the serviced filter bowl is filled with oil from the filtered side with a defined oil quantity of about 50-100 ml/min, the air in the filter bowl escapes (**Figure 8a**) through the opened vent valve. Once oil comes in contact with the vent valve (**Figure 8b**), the valve pin is pressed into the sealing area due to oil friction in the radial sealing gap.

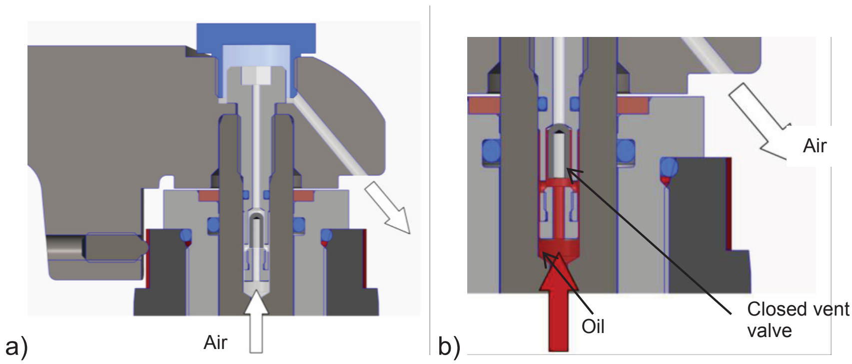


Figure 8: Automatic Ventilation. a) Vent Valve Opened, b) Vent Valve Closed

3.2. Pressure Drop Optimization

The volume flow from the pre-filtration side to the filtered side is controlled by large cross sections with only a few deflections.

The filter element is positioned eccentrically in the filter bowl (**Figure 9**); this leads to a reduction in pressure drop in the flow-gap by 2.5 times compared to a centrically positioned filter element.

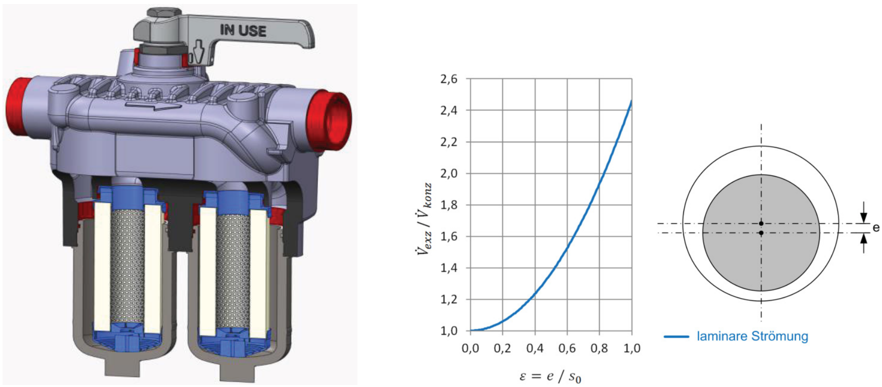
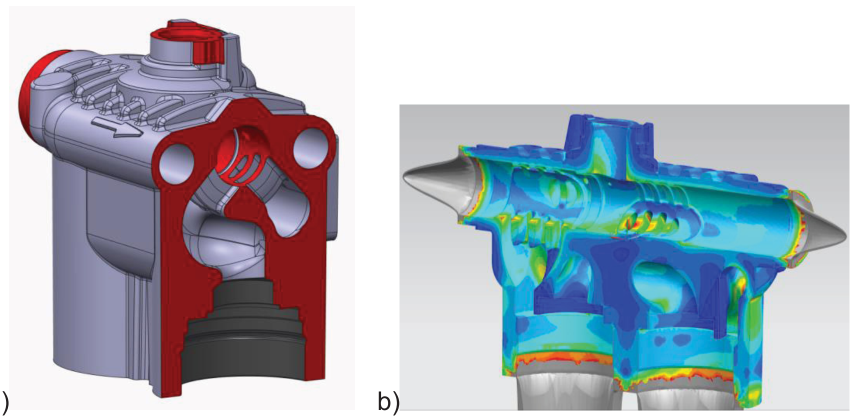


Figure 9: Filter Element Eccentrically Positioned inside the Filter Bowl /1/

3.3. Optimized Housing Structure

In order to reach a low total weight, FEM analyses (**Figure 10b**) are necessary. A reduced wall thickness can be achieved with the help of a housing design that mainly consists of cylindrical and spherical shapes (**Figure 10a**). Additional outer ribs add further stiffness to the housing.

a) b)



Figures 10: a) Optimized Housing Structure, b) FEM Calculation

4. Calculation and Validation

4.1. Ventilation

4.1.1. Calculation of the Ventilation

The pressure Force F_p (5) is a result of the pressure loss (3) in the gap at the sealing pin and was calculated with the help of the Bernoulli equation (3).

The weight force F_G (8) is calculated from the volume (7) of the sealing pin and the specific weight.

$$F_p \geq F_G \quad (1)$$

$$F_p = \Delta p \cdot A_D \quad (2)$$

$$\Delta p = \frac{96 \cdot l \cdot \rho_F \cdot v^2}{Re \cdot d_h \cdot 2} \quad (3)$$

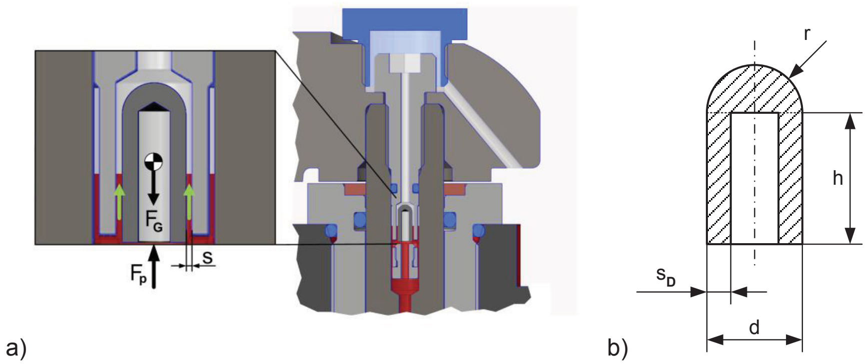
$$A_D = \frac{\pi}{4} \cdot d^2 \quad (4)$$

$$\boldsymbol{F_p = \frac{3 \cdot v \cdot l \cdot \rho \cdot Q \cdot d}{s^3}} \quad (5)$$

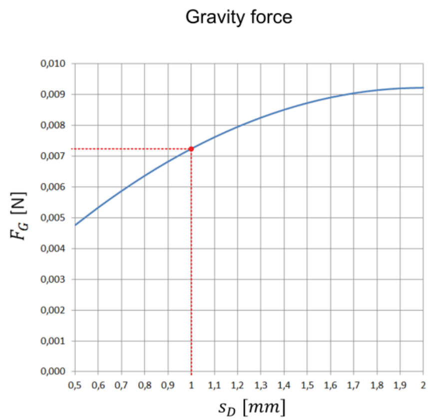
$$F_G = g \cdot \rho \cdot V \quad (6)$$

$$V = \pi \cdot d_m \cdot s \cdot h + \frac{2}{3} \cdot r^3 \quad (7)$$

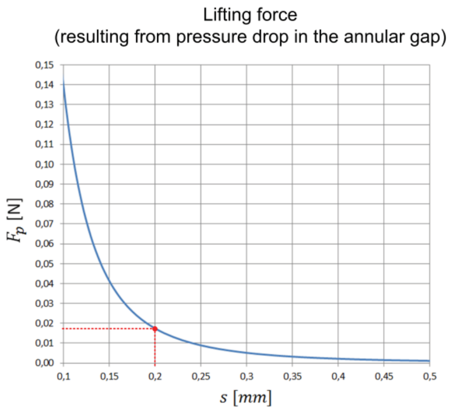
$$\boldsymbol{F_G = g \cdot \rho \cdot \pi \cdot \left(d_m \cdot s \cdot h + \frac{2}{3} \cdot r^2\right)} \quad (8)$$



Figures 11: a) Forces At The Vent Valve, b) Sealing Pin



a) $F_G = f(s_D)$ for $d = 4\ mm;\ h = 10\ mm$



b) $F_p = f(s)$ for $l = 8{,}2\ mm;\ Q = 10\ \frac{ml}{min};\ \nu = 10\ \frac{mm^2}{s};\ d = 4\ mm$

Figures 12: a) Gravity Force Dependent On The Wall Thickness Of The Sealing Pin,
b) Pressure Force Dependent On The Gap Width

In consideration of the relation between lifting force F_p and gravity force F_G in unfavorable conditions (low viscosity and low flow rate), the sealing element was designed with a safety factor of about 2:

Gap between sealing element and outer cylinder: s = 0.2 mm

Wall thickness of the sealing element: s_D = 1 mm

The following forces are in effect:

Lifting force: F_p (0.2 mm) = 0.017 N

Gravity force: F_G (1 mm) = 0.0072 N

4.1.2. Validation of the Ventilation

Test setup

Evidence of the automatic aeration and ventilation function was found with the help of a prototype (see **Figure 13**). Boring hole and sealing cone were drilled. The sealing cylinder with spheroidal face was turned. Aeration and ventilation were tested with maximum sealing gap between boring and sealing cylinder.

Test procedure

It was the objective of the test to determine the basic conditions in which the aeration and ventilation unit functions reliably. In order to do so, the following parameters were varied:

- system pressure (high, low),
- oil and air flow rate and
- viscosity of the oil.

Test Results

The valve closes under two conditions:

1. once an air flow of 1750 ml/min is reached,
2. once oil enters the sealing gap.

Oil viscosity was between 5 and 850 mm^2/min. The valve closed reliably at an oil flow of 12 ml/min.

Aeration function was affirmed after 96 h at 500 bar.

The valve's inertia is so low that it follows the pulsation of a gear pump. Leak tightness is 100 % guaranteed in these load conditions.

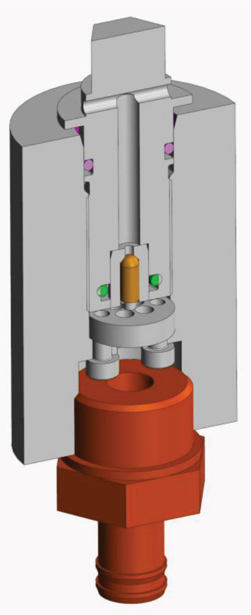


Figure 13: Aeration and Ventilation Unit

4.2. Validation of the Change-Over Process

Test Setup and Procedure

The change-over function was tested with a prototype (**Figure 14**). The general design and setup of the components involved in the change-over process were simulated in a simplified assembly. The change-over sleeve and the transfer elements were turned and milled.

The objective of the test was to simulate the change-over process as similar to series production as possible. The automatic pressure compensation between the sealing segments of the change-over sleeve and the 'inactive' filter bowl was simulated, as well as change-over forces in dependence of the differential pressure between the pre-filtration side and the filtered side.

Test Result

The pressure compensation via the pressure compensation bore which is opened automatically during the change-over process was accomplished. It was tested in the pressure range of 5 to 250 bar. Once the change-over process is complete the pressure compensation valve closes absolutely leak-tight. After pressure compensation, the change-over torque at the change-over shaft was below 40 Nm, at a differential pressure of 10 bar and a system pressure of 300 bar.

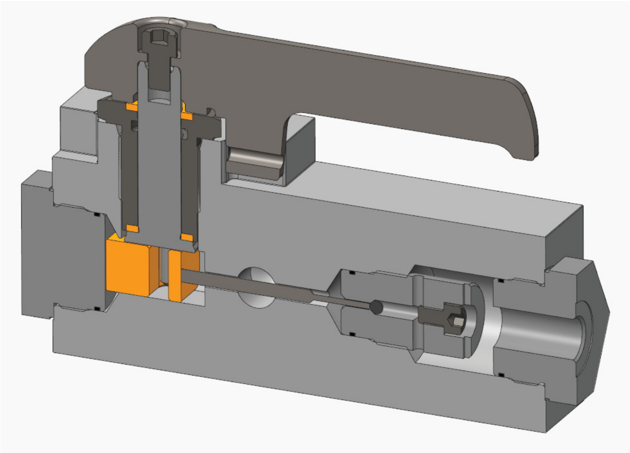


Figure 14: Pressure Compensation Test Unit

5. Summary

Filter element removal for today's Duplex filters involves a rather complex service procedure. Moreover, the pressure resistance - weight ratio is high. With the newly developed Duplex filter, all the processes that typically have to be carried out separately, such as pressure compensation, ventilation and refilling of the serviced filter bowl, are performed automatically as the change-over lever is operated. The pressure resistance – weight ratio could be lowered by combining cylindrical and spherical shapes with additional outer ribs.

The newly developed Duplex Filter is a trendsetter regarding filter element service, reduced pressure loss and a high power-to-weight ratio. The fool-proof filter element service is one highlight. It combines automatic pressure compensation and an automatic ventilation system. Thanks to the high transmission ratio only low change-over forces are necessary.

6. References

/1/ Bohl, Willi & Elmendorf, Wolfgang: Technische Strömungslehre. Stoffeigenschaften von Flüssigkeiten und Gasen, Hydrostatik, Aerostatik, Inkompressible Strömungen, Kompressible Strömungen, Strömungsmesstechnik. 14. Auflage. Würzburg: Vogel Industrie Medien GmbH & Co. KG, 2008.

7. Nomenclature

A_D	area (sealing element)
A_s	gap area
d	outer diameter
d_h	hydraulic diameter $(= 2 \cdot s)$
d_m	mean diameter $(= d - s_D)$
F_G	gravity force
F_p	pressure force
g	gravitational constant
h	height of the cylinder part
l	gap length
Q	flow rate
r	radius
Re	Reynolds number
s	gap width
s_D	wall thickness
v	velocity
V	volume
Δp	pressure drop
ρ_D	density (sealing element)
ρ_F	density of oil
v	kinematic viscosity