USE OF BROADBAND SILENCERS IN HYDRAULIC CIRCUITS TO REDUCE PULSATIONS

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ABSTRACT

New axial piston pumps with fixed displacement volumes, such as the high efficient power package (HEPP) pumps, operate at variable rotational speeds and thus variable flow rates in a wide range. Using intelligent pump control systems, small and light packages are possible. In contrast, the frequency of the fluid pulsations vary due to the rotational speed and have to be controlled avoiding stress or wear in the hydraulic system components (e.g. seals of tubing) and potentially impacting noise emissions.

Especially in mobile machines, the noise of a combustion engine drown out the noise of the hydraulic system. By replacing the combustion engines by electric drives, the fluid born noise (FBN) becomes audible.

Due to the excitation frequencies, a broadband silencer for high-pressure applications is required. This is realized by a Multi-Helmholtz-Resonator (MHR) concept within one cylindrical volume. The design will be adapted for pump-specific frequency characteristics in aircraft hydraulic conditions and fine adjusted during test verification by means of an adjustable tube-inside a pressure shell.

Keywords: Pulsation, Fluid Born Noise, Hydraulic Dampener, Silencer, Piston Pumps, Gear Pumps, Excitation frequencies, Resonance, Multi Helmholtz Resonator

1. INTRODUCTION

HYDAC Technology designs, produces and sells all kind of hydraulic accumulators such as diaphragm-, bladder-, piston- and metal bellows accumulators covering a standard pressure range up to 1,200 bar and volumes from 0.07 dm3 to more than 3,000 dm3. In addition to a classic integration of accumulators into hydraulic systems, the basic use as a hydraulic damper defines the HYDAC product category of hydraulic dampers, where the specific cause of the pulsation is taken into account.

The pressure ripples occurring in hydraulic systems vary in cyclical or one-off problems like those from displacement pumps, valve actuation or system start-up and shutdown. Based on the specific problems and the corresponding excitation frequencies, different hydraulic damper types are recommended. A distinction is generally made between the usage of the capacitive effect of gas volumes on the one hand and damping principles of the hydraulic liquid on the other hand.

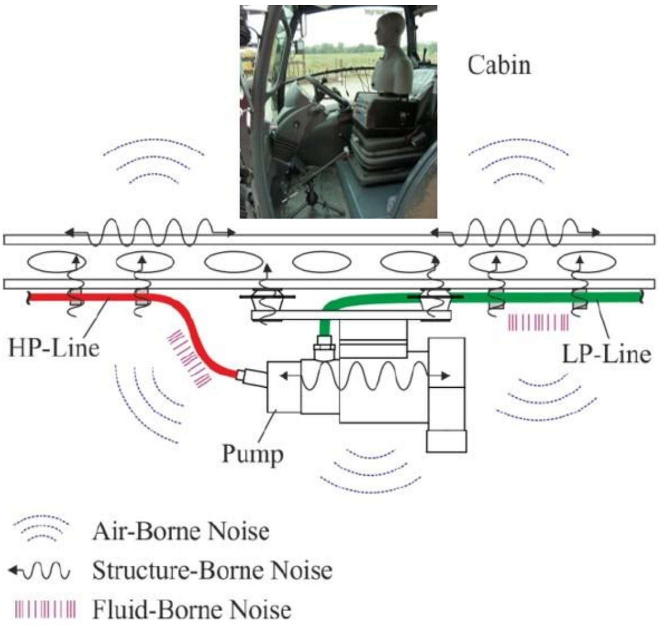

Figure 1: Noise measurement in a mobile application – figure modified taken from [1]

Two types of liquid dampers are frequently used and well known theoretically, Helmholtz Resonators and inline expansion chambers. HYDAC's silencer concept is a mixture of both types increasing the attenuation levels for the given envelope space. The functional technology is recommended for excitation frequencies above 175 Hz, which is typical for industrial axial piston pumps with corresponding displacement elements and rotational speeds. The presented broadband technology extends the damping effect from dedicated frequencies to a wider frequency range, which meets the requirements of variable speed pumps.

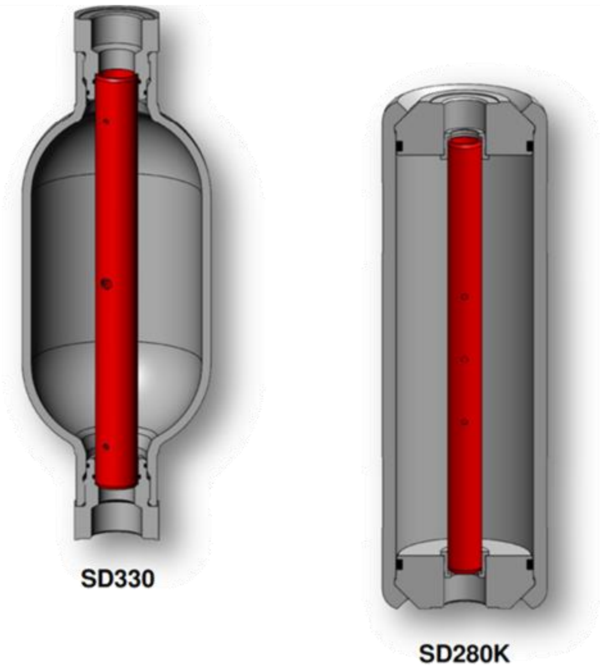

Figure 2: HYDAC industrial broadband-silencer types SD330 and SD280K

HYDACs broadband silencer design was adapted for pump-specific frequency characteristics in aircraft hydraulic conditions. Fundamental knowledge for the design of corresponding damper types was developed during investigations in the framework of aviation research projects funded by the ministry of economics of Germany (BMWi) [3, 4]. A main driver for the insertion tube design is the wide excitation frequency range of the axial piston pumps used. Tests accompanying the simulation to validate the complex internal processes are essential for product development of these damper types and model updating of the simulation.

2. DAMPING PRINCIPLES - BROADBAND SILENCER TECHNOLOGY

The basic principle of an inline Helmholtz-Resonator for HYDACs silencer technology was developed for more than 20 years and has been used successfully in industry ever since. Figure 2 illustrates the differences in damping level amplitude and bandwidth for an inline chamber and a single Helmholtz Resonator [1]. The silencer combines the possibility of an inline integration of the hydraulic damper in the hydraulic circuit with the higher damping levels of a Helmholtz-Resonator compared to an inline chamber.

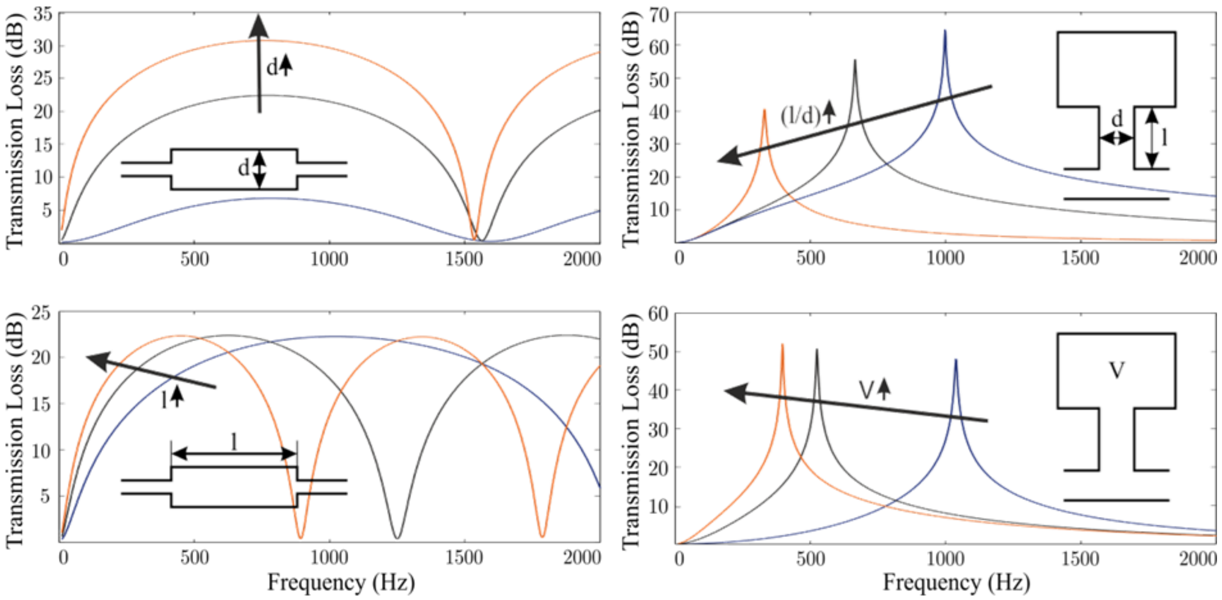

Figure 2: Different damping principles - figure taken from [1]

This is realized by integration of an insertion tube in an accumulator shell, separating one cylindrical volume representing the stiffness of a Helmholtz Resonator. Every radial bore of the insertion tube is linked to the neck of a Helmholtz Resonator and the cylindrical fluid inside acts as a point mass. Inertia and stiffness define the natural frequency of this single vibration absorber. The combination of different bores within one tube is the basis of HYDACs broadband silencer concept, achieving a sufficient hydraulic damping level over the frequency range due to superimposed Resonator effects. Due to the wider frequency bandwidth of aviation hydraulic systems, the number of required necks was extended to a sufficient level compared to the proven industrial design. This additionally requires the shift of the resonator frequencies to higher levels. The damping principle via parallel Helmholtz Resonators of the broadband silencer concept is hereby very robust against temperature fluctuations and the associated fluctuations of the speed of sound in the hydraulic fluid. This is a significant advantage in the aviation sector, where an operating temperature range from -55 to over 100 °C can be assumed.

Besides the positive impact on the fluid borne noise of the hydraulic system and the corresponding noise level within the passenger cabin, the service life and reliability of the existing hydraulic components inherent in the system can be increased.

3. TEST SETUPS

As mentioned before, the validation by test of the broadband silencer design is a main and important driver for the product development. The experimental analysis of hydraulic dampers requires a dedicated sinusoidal pressure ripple source, which is applied to the test object. The adjustability of the ripples amplitude and frequency are core requirements.

In general, two different types of hydraulic damper tests are possible. The silencer can be adapted directly to the axial piston pump to realise a high coupling of the damper to the pressure ripple source (see Figure 3), neglecting the inner length of the pump. Behind the damper, a measurement pipe with different pressure sensor positions allows the damping analysis for different frequency ranges. A big advantage is the elimination of influences of the transmission behaviour of further components in between. Otherwise, this could have a negative impact on the pressure ripple amplitude in the silencer (oscillation node). Nevertheless, it is not possible to determine reflection effects of the test bench setup in order to consider them when determining the damping performance.

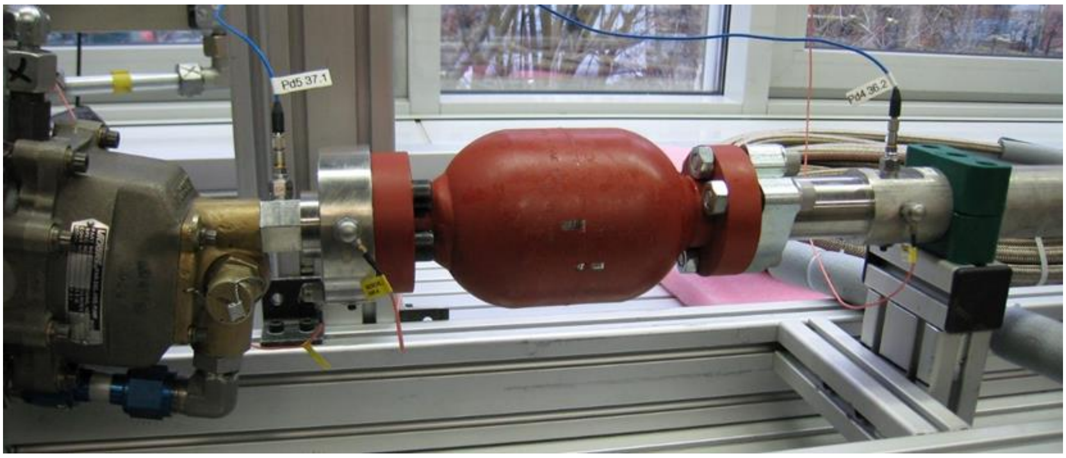

Figure 3: Aviation pump and directly flanged HYDAC standard silencer - FST TUHH test bench

For the possible high excitation frequencies of the pulsation ripples of up to 1.500 Hz in aviation high efficient power package (HEPP) systems, a modification of the test bench was necessary in addition to the broadband silencer design itself. In collaboration with the Institute of Aircraft Systems Engineering (FST) at the Hamburg University (TUHH), relevant components were modified, such as the measurement pipes and the rotary valve design (see Figure 4 and Figure 5).

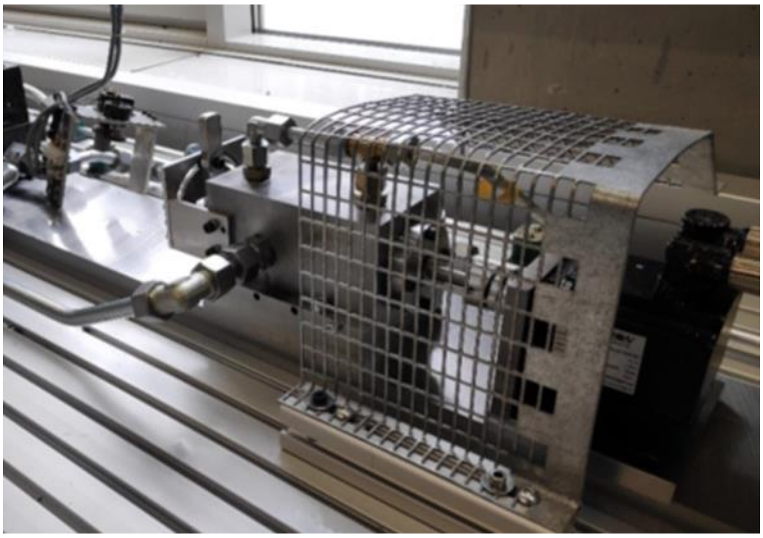

Figure 4: Integration of advanced rotary valve - FST TUHH test bench

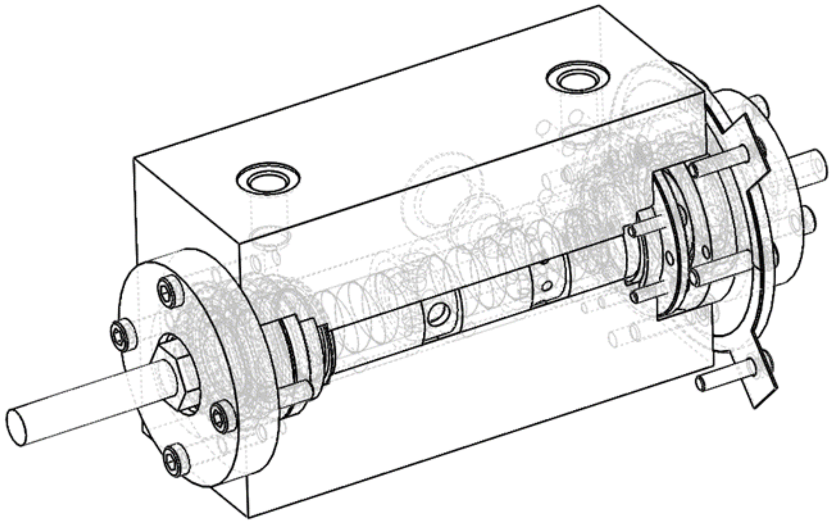

Figure 5: Semi-cut CAD line model of modified rotary valve

Alternatively, an additional measurement pipe can be placed in front of the silencer for high laminar inflow and additional sensor positions in front of the hydraulic damper (see Figure 6 and Figure 7). The flow ripple source is realized by the integration of a rotary valve for effecting the pulsation. The pump pulsations of the hydraulic power unit used upstream of the rotary valve is hereby levelled by the pipe distance to the hydraulic power source and an additional damper. Due to the distance between the pressure ripple source (rotary valve) and the test silencer, an impact on the measured pressure amplitudes for the different sensor positions remains in this test setup configuration. Different varying pulsation frequencies cause the variation of the wavelength of the pressure ripples and require the adaption of the sensor positions of both measurement pipes for the observed frequency range, which is illustrated in Figure 7. The movement of the oscillation nodes is clearly recognisable and important for the evaluation and interpretation.

Based on the second modified test setup with two measurement pipes, different damper volumes and insertion tube designs for the broadband silencer concept for aviation applications were tested and analysed at the Institute of Aircraft Systems Engineering FST at Hamburg University of Technology [7]. Figure 8 illustrates qualitatively the effect of a cylindrical resonance volume increase for the same insertion tube. It can be stated in principle, that a larger resonance volume increases the damping performance. Due to the logarithmic representation of the graphs, this applies in particular to the lower frequencies. For higher frequencies, the integration of hoses between hydraulic pump and damper is beneficial.

A further investigation of the variation of the fluid flow for laminar levels showed no major impact on the measured damping performance of the broadband silencers. In general, a laminar inflow is essential for a proper damping behaviour of this Multi-Helmholtz Resonator concept. Jumps in the area cross-section and corresponding turbulent flow decreases the performance and have to be avoided during hydraulic system conception and silencer integration.

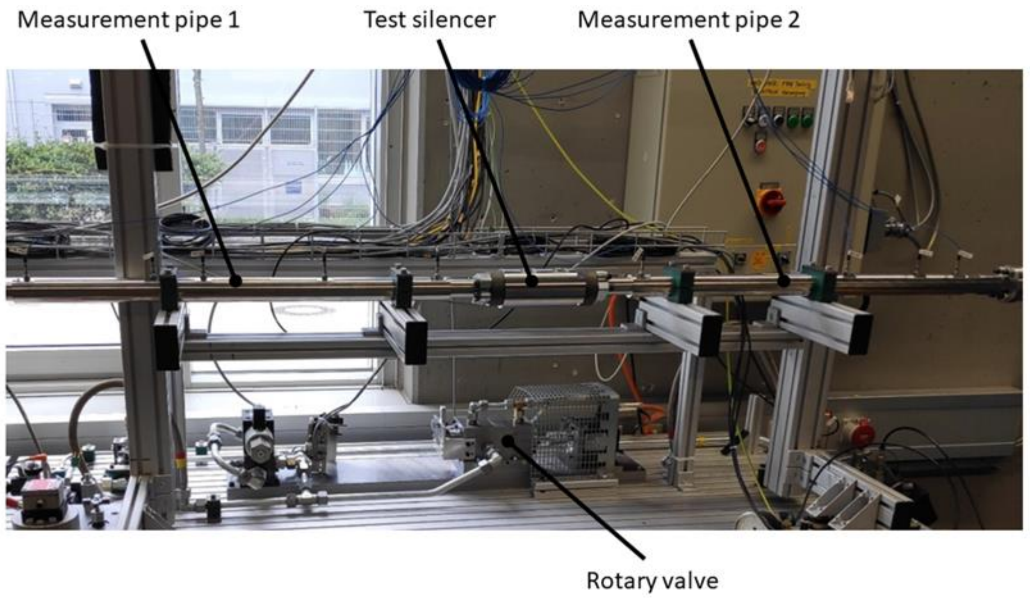

Figure 6: Test setup with two measurement pipes - FST TUHH test bench – figure taken from [7]

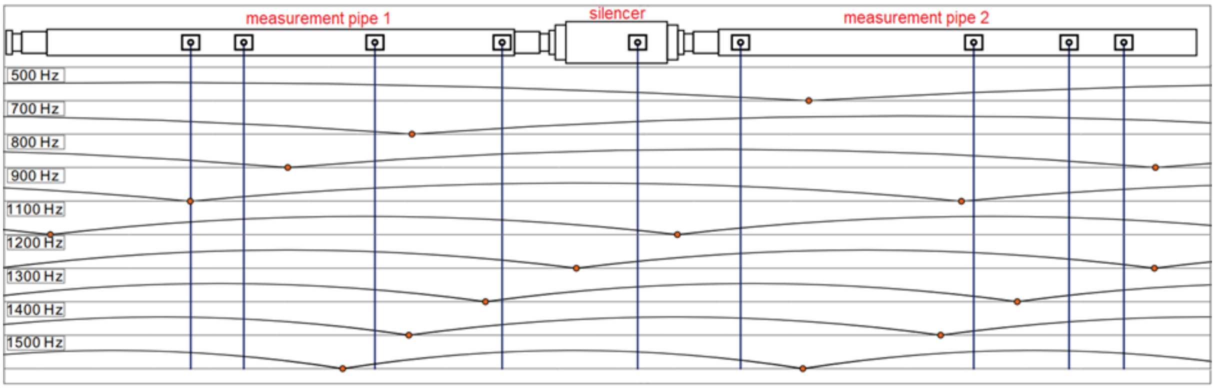

Figure 7: Pressure sensor positions of test setup and wavelength influence on signal strength - FST TUHH test bench – figure modified taken from [7]

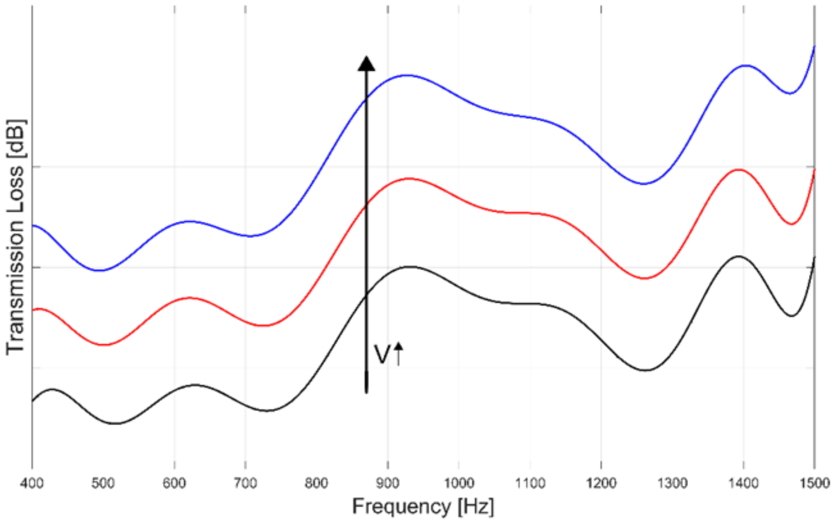

Figure 8: Qualitative influence of resonance volume on silencer damping performance

4. SIMULATION

Since 1997 HYDAC uses Hydroplus, a software developed at the University of Stuttgart. Unfortunately, this software was not updated anymore and therefor HYDAC switched to a new software package. The University of Bath offers a pressure ripple analysis software package (PRASP). A Matlab/Simulink® toolbox models FBN characteristics of hydraulic circuits. The fluid-borne noise characteristics of positive displacement hydraulic pumps can be measured using the Secondary Source test method. This forms the basis of British Standard BS6335 pt. 1 and ISO 10767-1: 2015 for the rating of pump fluid-borne noise. Hydraulic motors, valves and hoses can also be tested using this method [5].

Already during the aviation research projects in collaboration with the FST TUHH [3, 4], the modelling capability of the number of bores and corresponding Helmholtz chambers was studied for a filter silencer using PRASP (see Figure 9) and compared with corresponding test results [6]. This investigation was limited to two bores for one resonance volume. The modelling complexity of the superposition of many bores for one resonance volume for the broadband silencer concept is all the greater, as neither the direct combination of the bores in the model nor the separate consideration of the volume for each borehole reflects practice. In order to improve the current modelling and design development methods, targeted investigations on different insertion tubes are necessary. This concerns above all the effective capacity of the cylindrical resonance volume in the simulation model that is available for each bore with superimposed utilisation. This is a decisive issue for the methods of design finding, particularly with regard to the variance of the bore diameters and consequently the respective frequency effect of each individual resonator.

Besides the complex transmission behaviour of the broadband silencer itself, the hydraulic circuit with all components has to be implemented in a simulation model. The best possible positioning for maximum effectiveness in the system is the general aim of the system simulations. In general, for decoupling and improved damping, especially at higher frequencies, a hose between the pump and damper is common and expedient. But the conflicting objectives for the optimum distance in the frequency range remain the same as in the test setup. In addition to the aforementioned position dependence of oscillation nodes for different excitation frequencies, the temperature also has an influence on the density of the fluid and thus the speed of sound. This change in turn causes an adaption of the wave structure. Hereby, the requirements in the aviation sector clearly outweigh those of stationary industrial hydraulic systems. Consequently, the simulation-based investigation of main influencing factors is relevant for the success of the damper integration on system level. The best damper design loses its favourable effect if it is located at an oscillation node.

This requires the most accurate possible description of the transmission characteristics in the system design, including pump and hose modelling. This is to be able to estimate the influence on the hydraulic sound velocity on system level reasonably. With the help of PRASP and its integrated empirical values in hose modelling, the system-relevant verification process is to be advanced before the respective system is set up. Research is still needed, especially with regard to the visualisation and consideration of turbulent flow phenomena.

The overriding factor here is always the reduction of time-consuming measurement campaigns through predictions that are as precise as possible and ideally, only the need of a final prototype measurement is the declared objective.

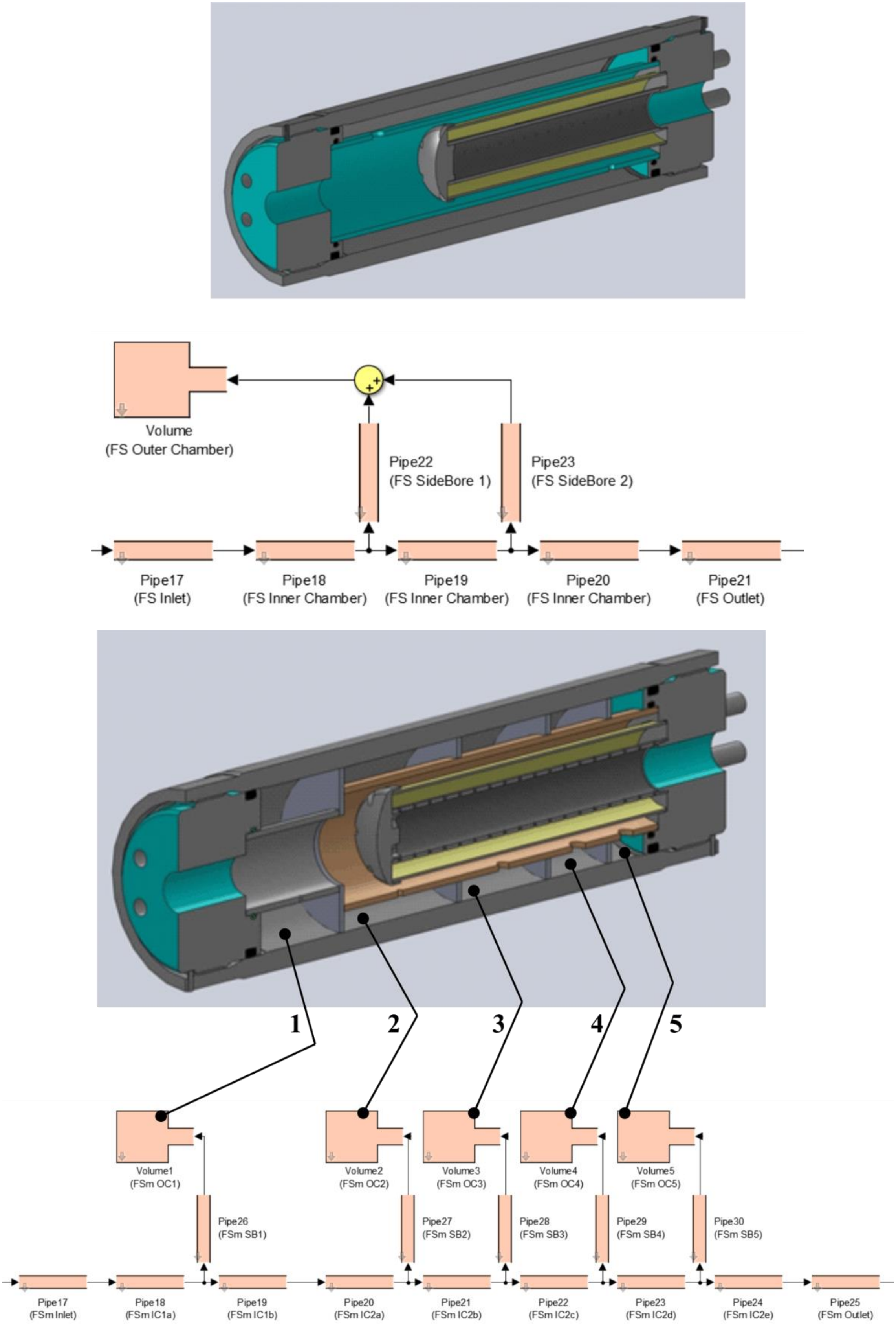

Figure 9: Filter-Silencer PRASP model with one Helmholtz chamber and two bores (top) and five Helmholtz chambers and five bores (bottom) - figures taken from [6]

5. ADDITIVE MANUFACTURING

During the R&D programs ELENA [3] and SINHUS [4] HYDAC produced first samples of the dampeners by additive manufacturing. The first sample was a Helmholtz Resonator which was manufactured in titanium by additive manufacturing and high strength corrosion resistant steel (CRES) by conventional processes (electron beam welding).

Figure 8: Helmholtz Resonator - conventional and additive manufacturing

The sample from CRES showed a mass of 0.400 kg compared with the titanium one of 0.230 kg. The material costs for both are similar, because the mass of the steel bar used for the conventional design is much higher than the amount of powder used in the stereolithography process (STL).

The main advantage of additive manufacturing is the chance to choose complex designs, which cannot be produced by conventional processes or only with an excessive effort.

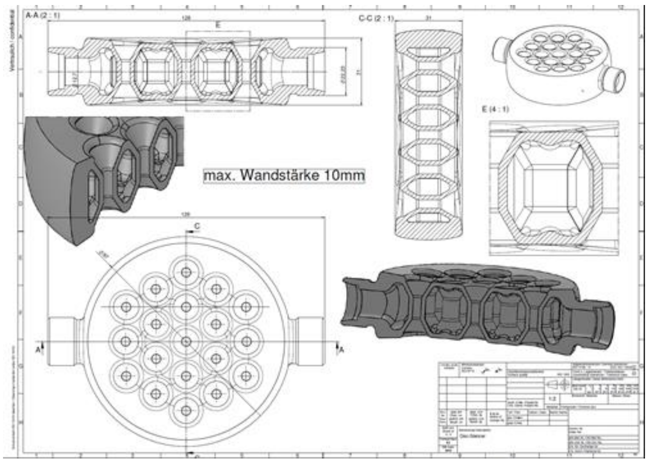

Figure 9: Disc Silencer – produced by additive manufacturing (STL)

The increased productivity of the STL process combined with a high process stability and a reduction of costs for the metal powders leads to a commercially attractive process opening the field for completely new designs.

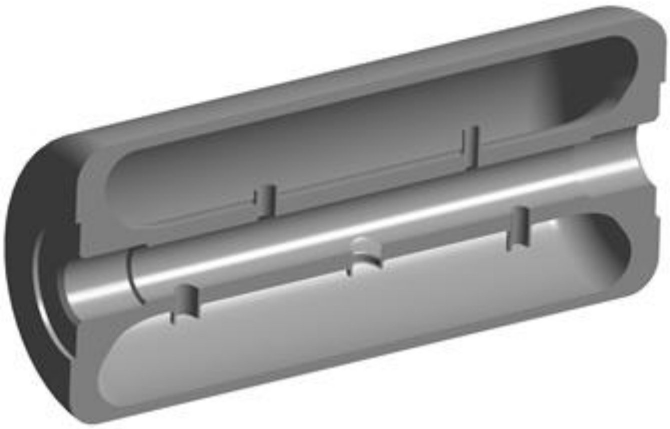

Figure 10: Broadband Silencer – produced by additive manufacturing (STL)

6. SUMMARY AND CONCLUSION

HYDAC has more than 20 years of experience using silencer technology in different hydraulic circuits and applications, mostly in industrial and mobile applications. This high reliable and energy efficient passive damping technology has been adapted to the requirements in aviation applications, e.g. high efficient power packages (HEPP). Low maintenance efforts lead to a minimum of service life costs. Dispensing a sealing system and without the necessity of gases there is no wear and no contamination of the hydraulic fluid and the corresponding hydraulic system. The different hydraulic connection options for the used inner free diameters of the system allow a minimization of additional pressure drops.

The simulation modelling of the complex damping behaviour of Multi-Helmholtz Resonators is still ongoing research due to its interaction phenomena. Further variation options for the neck lengths of the insertion tube bores and the corresponding single Helmholtz Resonators will be given by the integration and investigation of ALM-manufactured insertion tube designs.

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