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Damping of Pressure Pulsations in Mobile Hydraulic Applications by the Use of Closed Cell Cellular Rubbers Integrated into a Vane Pump

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Abstract

The present study evaluates the potential of a bio-inspired pulsation damper in a vane pump used in mobile hydraulic applications. Pressure pulsations caused by such positive displacement pumps can lead to malfunctions and noise in a hydraulic system. A common measure to reduce pressure pulsations is the integration of pressure pulsation dampers downstream of the pump. This type of damping measure can also be found in biology as *e.g.* in the human blood circulatory system. Such working principles found in living organisms offer a high potential for a biomimetic transfer into technical applications. The newly developed bio-inspired damper consists of cellular rubbers with non-linear viscoelastic material properties. In order to evaluate the new damping method, pressure pulsations were measured at two different back pressures and at a wide engine speed range of the vane pump. For further assessment, different setups, varying the stiffness of the cellular rubber materials and the damper volume, were tested. Within the tested back pressures, the pressure pulsations could be reduced by up to 40%. The developed integrated pulsation damper offers a high potential to dampen pressure pulsations of positive displacement pumps used in mobile hydraulic applications operating below 10 bar.

Keywords: pressure pulsations, pressure ripple, vane pump, bio-inspired pulsation damping, cellular rubbers, flexible foams

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1 Introduction

In mobile hydraulic applications, as for example in the oil circuit of passenger car combustion engines or power steering systems, requirements on the provided oil pressure and oil flow rate are very high[1]. As a result, variable displacement pumps are fitted that are able to deliver on demand volume flow rates functionally needed[1].

Due to their working principle, positive displacement pumps deliver a pulsatile flow, which leads to pressure pulsations (also known as fluid-borne noise). Hence, they often are the main source of noise and vibrations in a hydraulic system[2–4]. Furthermore the pulsations lead to dynamic loads increasing wear[5,6].

A measure, widely used in hydraulics, is the integration of pulsation dampers downstream of the pump, either in a side branch or inline configuration[3,5,7–13], or integrated into the pump outlet[3,4,14,15]. The requirements on pulsation dampers used for mobile hydraulic applications are very high as the pump is often driven by a combustion engine with variable driving speed and the dampers have to work reliably over a broad range of frequencies and working pressures[3,5,16].

Pulsation dampers are typically categorized in absorption and interference type dampers or mixtures of both[3,5,7]. The absorption principle is characterized by the dissipation of part of the energy of the pulses into heat by fluid friction or internal material friction[5]. The interference or reflection principle makes use of destructive interference by superposition of waves with a 180˚ phase difference[3,5] induced *e.g.* by one or more changes in pipe diameter or by application of a tap line[5,7,16]. Typical damping factors range from 10 dB to 40 dB or higher[5,7] (see Eq. (1), section 2.3.4).

Common pulsation dampers like hydraulic accu-

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mulators for example often are too big to be integrated into mobile hydraulic systems, they may not work over the required broad frequency range or they have a negative effect on the system dynamics (pressure build up in system)[3,5,15–17].

Pumps with integrated pulsation dampers that are suitable for the use in mobile systems can be found in high-pressure gasoline direct injection systems[4,14,18] and power-steering hydraulic circuits[3,16]. These diaphragm-based or membrane-type dampers consist of a pressurized gas-filled chamber enclosed by two metal diaphragms or a metal membrane combined with a hydraulic accumulator respectively. Nevertheless, integration in oil pumps of combustion engines may prove difficult as these dampers require a relatively large space. A compact damper based on a pressurized rubber bladder embedded in an axial piston pump was developed by Chai *et al*.[15]. The pulsations were attenuated by about 35%.

New concepts on how to dampen pressure pulsations of pumps can also be found following biomimetic approaches since the delivered flows by pumps found in nature are also mostly pulsatile[19]. A promising concept generator in this context is the closed circulatory system of vertebrates consisting of the heart, a variable valve- and -chamber pump, and a highly branched distensible elastic blood vessel system[20].

Bach *et al*. compared the underlying damping principle of the circulatory system of vertebrates with existing technical solutions and suggested that the non-linear viscoelasticity of the vessel walls[21–23] of arteries offers a high potential towards improving existing technical dampers or finding novel biomimetic damping solutions[19]. Similar to technical pumps, the heart of vertebrates delivers a pulsatile flow. The magnitude of the pressure pulsations in the circulatory system is reduced and the blood flow is smoothed throughout the system due to the passive expansion and elastic recoil of the arterial walls of the major vessels[20]. The vessel walls represent a composite material, composed of elastin and collagen fibres and smooth muscle cells[24,25]. Part of the pulse energy is dissipated by the viscoelastic component of the vessel walls (about 15% – 20% strain energy is lost during each cycle)[20]. The underlying damping principle is comparable to the one of expansion hoses and inline hydraulic accumulators[19].

The present study investigates the pulsation damping potential of a bioinspired pulsation damper with closed cell cellular rubber foams exhibiting a non-linear viscoelastic material behaviour[26] similar to the one reported for vessel walls of arteries. The damper is directly integrated into the outlet of an oil pump used in oil circuits of combustion engines in a side branch configuration and features a simple design. In spite of introducing an additional hydraulic capacitance to the system by using air or nitrogen, as commonly done in most technical dampers, the presented damper makes use of the compressibility of closed cell cellular rubber foams. Various patents have been granted for compact damping devices with a similar design making use of cellular elastic or rubber materials *e.g.* in electronically regulated braking systems (side-branch configuration)[27–29]; and other hydraulic systems of motor vehicles (inline configuration)[30,31]. However, these dampers are not directly integrated into the pump itself and to our knowledge there exist no studies covering systematic changes of the damper composition and type of material used, other than for in-line hydraulic suppressors with a solid compressible liner mounted after the pump[11,32].

Consequently, this study sets out to determine the main influence parameters on the damping behaviour of the proposed pulsation damper by varying the material, number of damping elements, the pump back pressure and pump driving speed for the application in low pressure (< 10 bar) mobile hydraulic systems (*e.g.* oil circuit of combustion engines of passenger cars).

2 Materials and methods

2.1 Pump and damping materials

Pump:

All experiments were performed with a variable displacement vane pump with seven vanes (passenger car oil pump used for diesel engines, maximum pump capacity: 18 cm^3 per revolution). The pump was chosen as a model pump since it represents a typical type of pump used in oil circuits of combustion engines of passenger cars[1]. Depending on the engine's operating conditions, it typically runs at 750 rpm to 5500 rpm and delivers a volume flow rate of about 0 $L\cdot min^{-1}$ to 40 $L\cdot min^{-1}$. The mean operating pressure at the pump outlet varies between 0.5 bar and 6 bar.

The pump operates in two different engine pressure stages (pressure after oil has passed the oil filter/oil cooler module), the low-pressure stage, with an oil