

Advances in Fluid Power Systems

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1. Special Issue Information

The main purpose of this special edition of “Advances in Fluid Power Systems” was to present new scientific work in the field of fluid power systems for the hydraulic and pneumatic control of machines and devices that are used in various industries. The development work of authors from various research centres have been published. Fluid power systems (hydraulic and pneumatic drives and their control) involve the use of fluid properties to generate, control, and transmit power using pressurized fluid flow. Fluid power systems are simple and easy to use, capable of accurately controlling the position, speed, force, and torque in machines, and are economical and safe to operate. The fluid power system research sector is currently undergoing tremendous expansion, invigorating strategic companies, power engineering, the oil and gas industry, the mining industry, the steel industry, and metal processing in the machine industry. High-pressure hydraulic forging presses are used for open-die forging of heavy steel forgings (carbon, alloy, high-alloy, stainless, and other steels) for large-size hot forged products, which include turbine shafts (water, gas, steam), rotors for wind and gas power generators. These products find buyers mainly in the shipbuilding, machinery, energy, and metallurgy industries. There are several main challenges for fluid power systems, such as increasing energy efficiency, improving reliability, building smart components and systems, reducing the size and weight of components, reducing environmental impact, improving the capabilities for recovery and storage of energy for reuse, digitalization, and 5G wireless connectivity of smart components. Advances in fluid power systems are leading to the creation of new smart devices that can replace tried-and-true solutions from the past. This special issue focuses on the recent advances and smart solutions for fluid power systems in a wide range of topics, including:

- Fluid power to the IoT and Industry 4.0: smart fluid power technology, wireless 5G connectivity in fluid power, smart components, and sensors.
- Fluid power in the renewable energy sector: hydraulic drivetrains for wind power and for wave and marine current power, and hydraulic systems for solar power.
- Fluid power hybrid: hybrid transmissions, energy recovery and accumulation, energy efficiency of hybrid drives.
- Industrial and mobile fluid power: industrial fluid power solutions, mobile fluid power solutions, energy efficiency solutions for fluid power systems.
- Environmental aspects of fluid power: hydraulic water control technology, noise and vibration of fluid power components, safety, reliability, fault analysis, and diagnosis of fluid power systems.
- Fluid power and mechatronic systems: servo-drive control systems, fluid power drives in manipulators and robots, fluid power in autonomous solutions.

2. Published Papers

Filo et al. presented the results of a computational fluid dynamics (CFD) analysis of an innovative directional control valve consisting of four poppet seat valves and two



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electromagnets enclosed within a single body [1]. The valve has a unique design, allowing the use of any poppet valve configuration. Seat valves that are normally opened (NO) and normally closed (NC) can be used. The combination of four universal valve seats and two electromagnets gives a wide range of flow path configurations. This significantly increases the possibility of practical applications. However, due to the significant miniaturization of the valve body and the requirement to obtain necessary connections between flow paths, multiple geometrically complex channels had to be made inside the body. Therefore, the main purpose of the work was to shape the geometry of the flow channels in such a way as to minimize pressure losses. During the CFD analyses, the dissociation velocity in the flow channels and the pressure distribution on the walls were determined. The results were used to obtain the pressure loss as a function of the flow rate, which was then verified by means of laboratory experiments conducted on a test bench.

The aim of Basiak's study was to develop a mathematical model for non-contact face seals to analyse the influence of thermoelastic phenomena on their operation [2]. The model was used to solve thermal conductivity and thermoelasticity problems. The primary goal was to calculate the thermal deformation values of the sealing rings in a non-contacting face seal with a flexibly mounted rotor (FMR) for a turbomachine. The model assumes the conversion of mechanical energy into heat in the fluid film. The heat flux generated in the fluid film is transferred, first to the sealing rings, and then to the fluid surrounding them. The asymmetric distribution of the temperature within the sealing rings leads to the occurrence of thermal stresses and, consequently, to a change in the geometry of the rings. The model is solved analytically. The distributions of the temperature fields for the sealing rings in the cross sections are calculated using the Fourier-Bessel series as a superficial function of two variables (r, z). The thermo-elastic problems described by the Navier equations are solved by applying the Boussinesq harmonic functions and Goodier's thermo-elastic displacement potential function. The proposed method involves solving various theoretical and practical problems of thermoelasticity in FMR type non-contacting face seals. The solution for the mathematical model made use of analytical methods, and the most important results obtained are presented in graphical form, such as the temperature distributions and axial thermal distortions in cross-sections of the rings. The calculated thermal deformations of the sealing rings are used to determine the most important seal performance parameters, such as leakage rate and power loss. The article also presents a multi-criteria analysis of seal-ring materials and geometry, making it easier to choose the type of material used for sliding rings.

Szumska et al. presented driver behaviour as one of the most important factors affecting road safety [3]. Many traffic situations require that a driver recognize a possible danger. In numerous works, aggressive driving is understood as unsafe and as a hazard entailing the risk of potential crashes. However, traffic safety is not the only thing affected by the driving style of a vehicle operator. Driver behaviour also impacts the operating costs of a vehicle and the emission of environmental air pollutants. This is confirmed by numerous works devoted to the examination of the effect of driving style on fuel economy and air pollution. The objective of this study was to investigate the influence of aggressive driving on fuel consumption and air pollutants emission. The simulation was carried out based on real velocity profiles collected in real-world tests under urban and motorway driving conditions. The results of the simulations confirmed that an aggressive driving style causes a significant increase in both fuel consumption and emission of air pollutants. This was particularly apparent in urban test cycles, where aggressive driving style resulted in higher average fuel consumption and pollutant emissions, as much as 30% to 40% above the average for calm driving.

Grybos et al. demonstrated how to reduce the level of noise from the expanded air from pneumatic tools [4]. Instead of a muffler, an expanded collecting system was proposed, where the air expands through the pneumatic tube and expansion collector. A mathematical model was developed which illustrates the dynamics of the air flow, as well as the acoustic pressure at the end of the tube. The computational results were compared with

experimental data to check the air dynamics and sound pressure. Furthermore, the study presents the methodology for measuring noise generated with a pneumatic screwdriver in a quiet back room and on a window fitting stand in a production hall. In addition, noise measurements were made for the pneumatic screwdriver and the pneumatic screwdriver on an industrial scale. These measurements demonstrated a reduction in the noise of pneumatic tools when the expanded collection system was used. When the expanded collecting system was applied to the screwdriver, the measured sound pressure level (SPL) decreased from 87 to 80 dB (A).

Sliwinski described a method for determining the theoretical and actual working volume of a hydraulic motor [5]. The new proposed method is based on the characteristics of the effective absorbency of the motor. Effective absorbency has been defined as the ratio of the flow rate of a motor to the rotational speed of the motor shaft. It has been shown that effective absorbency is a non-linear function of rotational speed and a non-linear function of pressure drop in motor working chambers. Furthermore, it has been proven that the actual working volume of a motor is a function of a third degree of pressure drop in the working chamber of the motor. The actual working volume should be taken to assess the mechanical and volumetric energy losses in the motor. Furthermore, the influence of the flowmeter location in the measurement system and the compressibility of the liquid on the result of the theoretical and actual working volume calculation was also considered and is described in this article. Differences in the assessment of the volumetric efficiency were also shown by assuming theoretical and actual working volumes.

Krzysztofik et al. investigated the sensitivity (resistance) of a quadcopter on-board gyroscope system, for the observation and tracking of a moving ground target, to changing parameters of its regulator under interference conditions [6]. It was shown that the gain in matrix elements is very sensitive, and even a slight deviation from optimal values can lead to reduced target tracking efficiency and the loss of control system stability. Furthermore, the authors studied the energy expenditure at various gyroscope system control parameter values, while homing a quadcopter onto a ground target. A Matlab/Simulink environment was used to perform simulations of the dynamics of the controlled gyroscope system. Selected test results are shown in graphic form.

Fabis-Domagala et al. proposed the use of matrix analysis and statistical methods to perform a simplified RCA (Root Cause Analysis) and to classify potential failures for a variable delivery vane pump [7]. The presented methodology is an extension of matrix FMEA and allows for prioritizing potential failures and their causes in relation to functions performed by pump components, the end effects, and the defined symptoms of failure of the vane pump.

Gapinski et al. presented the concept of controlling the designed optoelectronic tracking and scanning seeker [8]. The device described above is intended for the so-called passive guidance of short-range anti-aircraft missiles to various types of air manoeuvring targets. In the presented control method, the modified linear quadratic regulator (LQR) and the estimation of input signals using the extended Kalman filter (EKF) were used. LQR regulation utilizes linearization of the mathematical model of the seeker mentioned above by means of the so-called Jacobians. To improve the stability of the seeker control, the selection of vectors of signals received by the optoelectronic system was used, which also utilized EKF. The results of the research are presented in a graphical form.

Pan et al. presented a new type of electronic oxygen regulator (EOR) for use in oxygen equipment for aviation, that uses a technology where electronic servo control of the gas pressure of controls the gas pressure during breathing [9]. In this paper, the control method of EOR was studied and a dynamic model of the aircraft oxygen system was established. A disturbance-observer-based controller (DOBC) was designed using the backstepping method to achieve the goal of stable and fast breath pressure control. A sensitivity function was proposed to describe the effect of inspiratory flow on breath pressure. Combined with the analysis of the frequency domain of the input sensitivity function, the parameters of the DOBC were analysed and designed. Simulation and experiment studies were carried

out to examine the control performance of the DOBC in respiratory resistance and the positive pressurization process under the influence of noise and time delay in the discrete electronic control system, which could meet the physiological requirements of aviation. The research results not only verified the rationality of the application of the DOBC EOR in EOR breath control, but also proved the effectiveness of the control parameter design method according to frequency domain analysis, which provided an important design basis for the subsequent study of EOR.

Luo et al. presented the simulation platform of the molten salt reactor (MSR) plant developed to study the control characteristics under normal and accident conditions [10]. In the platform, a nonlinear dynamic model of the whole system was built consisting of a liquid fuel reactor with a graphite moderator, an intermediate heat exchanger, and a steam generator. A new control strategy based on a combined feed-forward and feedback scheme is presented, where a power control system and a steam temperature control system were designed to regulate load changes in the plant. Three different types of operation conditions were simulated with the control systems, including transients of normal load-follow operation, a reactivity insertion accident, and a loss-of-flow accident. The simulation results showed that the developed control system not only had a fast load-following capability during normal operation, but also had good control performance under accident conditions.

Sliwinski et al. presented new methods to determine the pressure drop in the internal channels of a hydraulic motor [11]. Mathematical models of pressure losses in internal channels are also described. Experimental tests of the satellite motor were carried out according to one of the proposed methods. The tests were carried out for two liquids, i.e., water and mineral oil. Experimental studies have shown that at a high flow rate in a motor supplied with water, the pressure losses are a dozen or so percent greater than in a motor supplied with oil. However, at low flow rates, the inverse is true; that is, the pressure losses in the motor supplied with water are about 10% lower than in the motor supplied with oil. A CFD calculation of the pressure drop in the internal channel of the motor was also performed. It was assumed that the holes in the commutation unit plate are placed face-to-face and that the liquid did not cause changes in the volume of the working chambers. In this way, it was proven that those simplified assumptions can have up to a 50% difference in relation to the experimental tests.

Fabis-Domagala et al. presented a FMEA analysis as a quality improvement tool that has been widely used for decades [12]. Its classical version prioritizes the risk of failure by risk priority number (RPN). The RPN is a product of severity (S), occurrence (O), and detection (D), where all factors have equal levels of significance. This assumption is one of the most criticized drawbacks, as it has given unreasonable results for real-world applications. RPN can produce equal values for combinations of risk factors with different risk implications. Another issue is the uncertainties and subjectivities of the information employed in the FMEA analysis that may arise from the lack of knowledge, experience, and linguistic terms used. Many alternatives to risk assessment methods have been proposed to overcome the weaknesses of classical FMEA risk management, in which we can distinguish modification methods by RPN numbers of employing new tools. In this study, we proposed a modification of the traditional RPN number. The main difference is that severity and occurrence are valued based on subfactors. The detection number remained unchanged. Additionally, the proposed method prioritizes risk in terms of implied risk to systems by implementing functional failures (effects of potential failures). A typical fluid power system was used to illustrate the application of this method. The method showed the correct failure classification, which meets the industrial experience and other results of research on failures of fluid power systems.

Liu et al. presented a small modular dual fluid reactor as a novel variant of the Generation IV molten salt reactor and the liquid metal fast reactor [13]. In the primary circuit, molten salt, or the liquid eutectic metal (U-Pu-Cr), is used as fuel, and liquid lead works as the coolant in the secondary circuit. To design the control system of such

an advanced reactor, the uncertainties of the computer model, and the physicochemical properties of the materials, must both be considered. In this paper, a one-dimensional model of a core is established, based on the equivalent parameters achieved via the coupled three-dimensional model and accounting for delayed neutron precursor drifting, and a power control system is developed. The performance of the designed controllers is assessed, taking into account the model and property uncertainties. The results achieved show that the designed control system can maintain the stability of the system and regulate the power as expected. Among the uncertain parameters considered, the fuel temperature reactivity coefficients have the greatest influence on the performance of the control system. The most optimized configuration of the control system is delivered based on uncertainty propagation characteristics using the particle swarm optimization method.

3. Conclusions

Trends in the development of fluid power systems are related to electronics, information technology, artificial intelligence, miniaturization, energy efficiency, environmental protection, and greater efficiency. The fluid power system industry aims to increase energy efficiency, improve operational reliability, use smart components and systems, reduce size and weight, and recover, store, and reuse energy.

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