An Approach to the Precise Dosing of Fluids

A. Müller, M. Gunkel, H. Kappler, T. Rolland

This document appeared in

Detlef Stolten, Thomas Grube (Eds.):
18th World Hydrogen Energy Conference 2010 - WHEC 2010
Parallel Sessions Book 5: Strategic Analyses / Safety Issues / Existing and Emerging Markets
Proceedings of the WHEC, May 16.-21. 2010, Essen
Schriften des Forschungszentrums Jülich / Energy & Environment, Vol. 78-5
Institute of Energy Research - Fuel Cells (IEF-3)
Forschungszentrum Jülich GmbH, Zentralbibliothek, Verlag, 2010
ISBN: 978-3-89336-655-2

An Approach to the Precise Dosing of Fluids

Axel Müller, **Michael Gunkel**, **Horst Kappler**, **Thomas Rolland**, Thomas Magnete, Herdorf, Germany

Abstract

Automotive dosing pumps have been available on the market for 25 years now. Initially used for fuel fired parking heaters in mobile systems – trucks, passenger cars e. g. –, this type of a reasonable dosing unit nowadays is applied in many fields. Based on the experience of delivering fuels, the dosing pump was advanced to deliver and admeasure more or less any kind of liquid media. One of the most innovative operational areas of such compact metering units is the fuel cell reformer technology, wherein a constant flow of a certain amount of fuel is desired.

This type of pumps combines the abilities of priming, delivering respectively metering of liquids, thus helping to optimize existent systems. Thanks to the characteristics of the compact dosing unit, complex hydraulic systems can be avoided. In contrast to separated systems for delivering fluids and metering them subsequently, the extensive integration of functions leads to less complex, more robust systems. Some components may become dispensable, such as sensors, shut-off valves or injectors. Thus, the amount of electrical and hydraulic interfaces may be reduced to the minimum, so that the total costs of the system become significantly lower.

Dosing units deliver fuel in a balanced manner. As they are designed as electromagnetically driven piston pumps, the piston is moved one to several times a second. The dosing pumps are able to pump a certain, small volume per stroke. Hence, based on this accurate volume, the total flow rate is determined by the frequency of the piston's movement only, which is the basis for easy control. This advantage, i. e. precise metering, is paid for with the disadvantage of the pulsing flow which is due to the principle of a piston pump. Current investigations into the flow characteristics show the significant potential which lies in the combination both principles: constant flow and precise metering. This effect can be achieved by designing the pump adequately or by using integrated attenuators. Based on relevant test results, potential influence factors, as counter pressure, temperature etc., are investigated into, too.

1 Introduction in Metering Units

Integrated piston-pumps for dosing fuel have been developed and manufactured in serial production for 25 years. Thomas started with the development and production in the mid-80s with the model "DP2". By using a special design of pump and actuator, the design of the "P450" is especially accentuated to this intention by reducing the stroke volume and the integration of an attenuator. Thus, the remaining pressure pulses are reduced over a wide range of temperatures, even with very low temperatures, so that they are not noticeable by the system. A second type series was initiated by Thomas Magnete in the early 1990s by developing the "P320" for heaters operated with Diesel fuels for Truck applications. In serial production since 1995, this original field of application was expanded and the “P320” soon became a basic dosing pump for several applications. This type is characterized by the robust design that simplifies the structure. Exceeding the ordinary arrangements for amelioration of serial products, the spectrum of power was extended significantly without enlarging the outer dimensions. The “P900” is a serial pump, specifically developed for aggressive and potential future fuels. Based on this, the prototype dosing units “P920” resp. “P923” are representing a new generation of pumps with an optimized design characterized by significantly smaller dimensions. Nevertheless, the performance of these prototypes is kept on the same high level or even meliorated.

Based on this, these types of dosing pumps are used for further applications. Prior to the year 2000, the use of the metering pumps using a piston pump-principle, was limited to the market for fuel operated heaters for mobile applications mainly. Since then, the specialized skills combined within these dosing pumps have been: priming, sucking, delivering, dosing/metering e. g. They enlarged the range of applications and enabled the optimization of existent facilities. Thanks to the sum of attributes, the compact dosing unit enables the designers to renounce complex, pressure-controlled metering systems. The widely advanced integration of functions and abilities makes many components dispensable. In contrast to separated systems for dosing and delivering liquids, expensive components as sensors, shut-off valves and injectors which have to be integrated costly, are not necessarily needed. By doing so, the total amount of electric and hydraulic and mechanical interfaces can be reduced to the minimum. This will lead to significantly reduced total weight, installation space, simplified fuel lines and total costs.

Auxiliary power units (APU) using fuel cells mostly need fuels in a special condition. Liquid hydrocarbons have to be converted into a gas mixture containing hydrogen by using a reformer. Trucks, aircrafts and cars usually have liquid fuels, Diesel e. g., aboard which have to be reformed before entering the fuel cell [5]. Hence, compact construction of the APU and the individual components and low weight are a necessity. According to [2], these systems may use Solid Oxide Fuel Cell (SOFC) technology. Such APUs are advantageous with regard to engine-independent availability of electrical functions, especially if highly integrated components are installed which fulfil all functions that are needed. Integrated shut-off valves guarantee safety under all critical situations, as no fuel can drop out of the fuel supply system. A valve at the outlet prevents gas from getting into the pump and the fuel supply system.

2 Mode of Operation

A solenoid driven actuator moves the metering system. Fig. 1 shows the actuator in a sectional view in normal position, i. e. not energized. Actuated by the solenoid, the pump’s piston is alternatingly being towed axially in the pump’s cylinder from the one end position to the other. The fluid is sucked into the pump through the filter by passing the sealing element. This sealing element is one of the safety features as it prevents medium from flowing backwards in case of a not-energized passive state of the metering unit. Subsequently, the fluid flows along the surface of the armature and pours into the cross-hole of the pump’s cylinder and then into the pump volume. This pump volume determines precisely the amount of the fluid which is emitted by each stroke of the dosing pump. In doing so, the fluid is passing another sealing element and the valve at the outlet, i. e. the pressure face.

The drive mechanism of the dosing unit operates by means of an electromagnet. By energizing the coil, the magnetic field establishes in the ferromagnetic circuit, see [1]. As the action of force is based on the ambition of the magnetic field to close the air gap between the pole and the armature, the slidable armature is moved in axial direction. Fig. 1 shows this air gap with the cone-shaped geometry. After switching off the voltage, the armature and the piston are towed back by the spring and achieve the normal end position again.

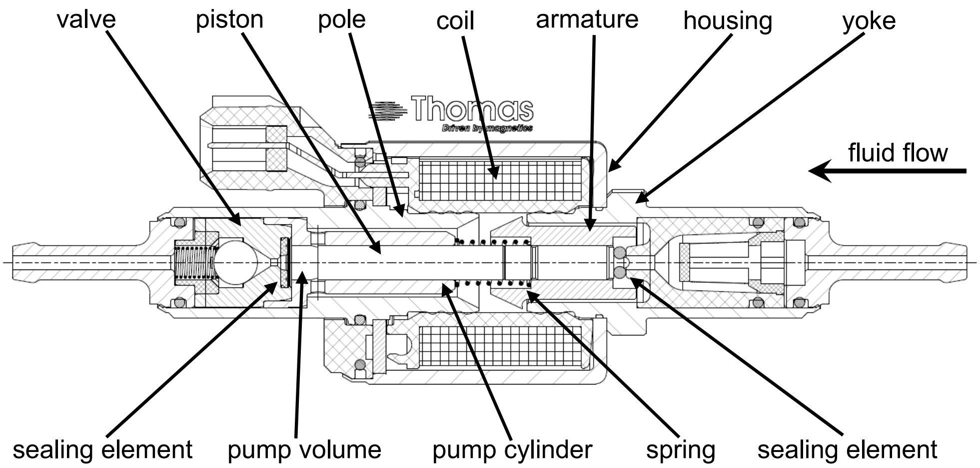

Figure 1: „P325“ sectional view, non-energized, normal position shown.

By applying the electric signal, the fluid is pushed through the thereby opened ball valve. Coming back to the normal end position, the pump can suck a further amount of fluid, as the ball valve at the outlet side closes and low pressure is generated within the pump volume. Once the piston passes the cross hole, further fluid can stream into that volume. With each electric pulse and depending on the control strategy, this sequence can be performed several times per second, each stroke emitting a fixed and exact volume. Thus, by controlling the driving clock frequency, the total amount of the metered fluid is ascertained.

3 Precise Fuel Delivery

As the precise flow rate is characterized by the exactly defined volume emitted per stroke, the clock frequency determines the total flow per time period. The graph shown in fig. 2 illustrates this linear correlation for two types of dosing units: high flow (“P325”; “P920”) and low flow metering pumps (“P450”; “P923”). Three parts of each type have been measured for this graph. Due to the fact that all these lines are lying upon each other, the excellent accuracy becomes obvious.

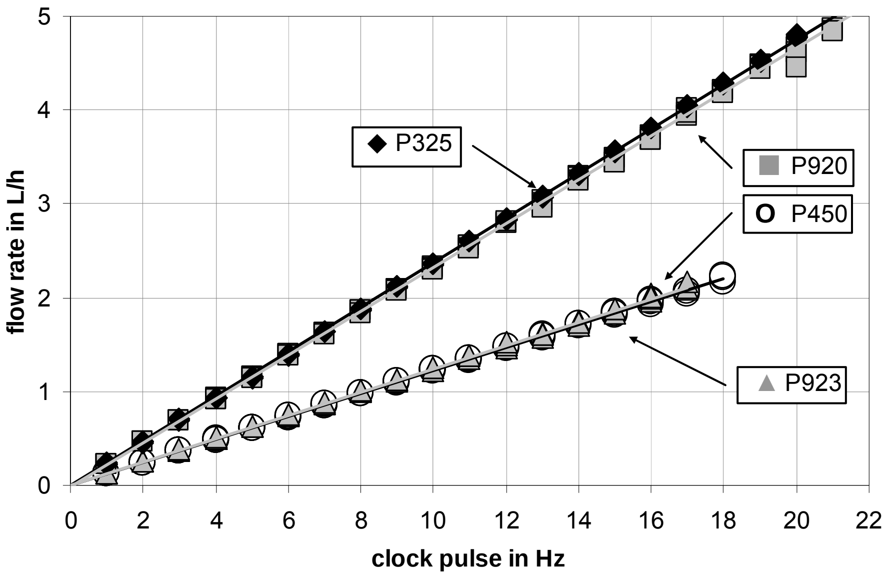

Figure 2: Characteristic curve: flow rate versus clock pulse.

For the investigation of the flow rate as a function of the clock frequency, the test set-up was chosen as follows: Each pump was actuated with a fixed voltage U = 12 V and the pulse width fixed at t_{ON} = 25 ms at ambient temperature. ARAL 4005 has been chosen for testing, as it represents a not-flammable liquid hydrocarbon. This fluid was sucked out of a beaker placed on a scale. The pump under test was positioned horizontally and adapted with an outlet line leading in a separate canister under atmospheric pressure condition. Each measurement run consisted of 100 individual shots performed with constant clock frequency. The flow rate, shown in fig. 2, is the averaged value of these shots, resulting from the mass difference recorded by the scale.

The fuel volume delivered by one single shot of the pump was determined. The pump under test was actuated for one stroke of the piston and sucked the test fluid out of a beaker, which was placed on a scale. The mass difference before and after the pump actuation was the base for the delivered volume per stroke V. The pump was operated with a low frequency f = 0.5 Hz [low flow pump] or f = 1.0 Hz [high flow pump], respectively, the voltage was U = 12 V with a pulse width of t_{ON} = 25 ms. The relevant data like the voltage U, the current I, the outlet pressure p_{out} and the mass of the test fluid m_{Fluid} was recorded continuously. All dosing units show a perfect accuracy from “shot to shot” with a standard deviation significantly less than 1 %. In absolute numbers, the volume delivered per stroke can be compared to a raindrop. According to literature [4], a typical raindrop is assumed to be in the size of 40 to 50 mm³ corresponding to the dimension of the delivered volume per stroke. Hence, the accuracy achieved has to be compared to one-hundredth of one raindrop only!

For a large number of applications, the average flow rate of several single shots is much more relevant than the consideration of one single shot. Each pump was actuated for 100 shots and the mass difference before starting the pump and after 100 shots was evaluated. By this method, the operation parameters of the pump could be modified in certain ranges. In Fig. 3, the measurement results for the different pump types, operated under the parameters – U = 12 V, t_{ON} = 25 ms, f = 10 Hz, p_{out} = 0 bar, are shown by presenting the difference of the averaged flow rate of 100 shots relative to the mean value of 200 repeated measurements. When regarding the average flow rate, the accuracy of the pumps is even significantly better than that of single shots. In field applications usually the averaged results should be considered for the layout of the corresponding system. The standard deviation of the metering pumps “P325” and “P450” was calculated with 0.15 % and does not exceed 0.31 %. Thus, the accuracy of the “average flow rate”, representing the main requirement for most field applications, is found to be at an excellent level.

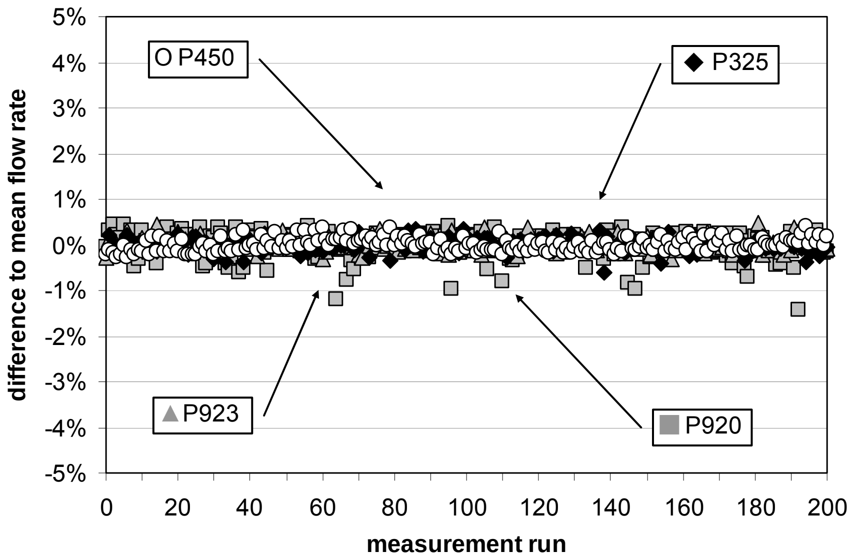

Figure 3: Accuracy of the averaged flow rate over 200 measurement runs, 100 shots each.

4 Precise Dosing Over Lifetime

Dosing units have to deliver the precise dosing during their lifetime. Hence, all pump designs were consequently tested in durability tests with different kinds of fuel, even Biodiesel-fuels containing aggressive substances. The global usage of metering units of that type requires robust designs and robust materials as they are in direct contact to the fluids. Well known for robustness, Thomas metering pumps available at the moment, are able to deliver all fuels that are commercially obtainable. For the future, investigations have been made to fulfil special demands for biomass fuels that potentially may degenerate. For that intention, test fuels have been used representing absolute worst case conditions, e. g. fuel blends like FAME containing water-, acid- and peroxide fractions. These test fuels are chemicals which are partly not available fuels and have to composed especially for these investigations. For example, the pump type “P320” ran in a durability test with ULSD (ultra low sulphur diesel) for a period time of 13,500 hours, actuated with a high frequency of f = 20 Hz. At the end of this durability test, approx. 1,000 million cycles, the deviation of the measured flow rate was less than 1.5 % relative to the nominal value. After dismantling the single parts of the pumps, every single part appeared like new, only minimal traces of use were recognizable. With the pump type “P900”, a durability test with aggressive diesel containing 20 % FAME, see [3], was performed at a temperature of $T_{Fluid} = T_{amb} > 50$ °C. The duration was 1,000 hours with a driving clock frequency of 17 Hz, i. e. 61 million cycles. The deviation of the measured flow rate after completion of the durability test was insignificant. All single parts of the pumps did not show any significant wear and have been found comparable to an unused condition.

5 Concluding Remarks

Excellent precision in metering characterizes the in-line dosing units. This precision is almost independent of the counter pressure and is guarantied for lifetime. Even a hypothetical chemical fluid, regarded to be the world’s worst fuel, was tested without harmful effects. After 1,000 h testing, the parts appeared like new. Also, a test for 13,500 h showed no degradation effects. Investigations into this bared an accuracy of considerably less than 1 % deviation from the mean flow. The averages of a preassigned number of strokes show even better results of less than 0.2 %. In addition to the accuracy, these in-line pumps show further special characteristics like self priming, robust design, high protection class and seal protection, high variability with regard to hydraulic and electric connectors. They are maintenance-free and designed for vehicle-lifetime as well.

For the usage within fuel cell systems and especially for the fuel delivery into reformers, Thomas metering pumps offer an integrated solution. No additional components, shut-off valves e. g., are necessarily needed. Thus, they offer a cost-effective solution ready for the market as 25 years of development and series production verify.

References

[1] Kallenbach, E. et al.: Elektromagnete [III]2008, Wiesbaden.

[2] Zizelman, J. et al.: Auxiliary Power Units with Solid Oxide Fuel Cell Technology for Independent Electric Power Supply in Passenger Cars, in: Fuel Cell World Proceedings 2002, pp. 306.

[3] Müller, A. et al.: Dosierpumpen: Neue Potentiale im Spannungsfeld zwischen Komfort und weltweiter Standardisierung, in: Hofhaus, J. (Ed.): PKW-Klimatisierung VI, 2010, pp. 174.

[4] Tabellen für die Rezeptur, Tropfentabelle DAC 2006.

[5] Peters, R.: Auxiliary Power Units for Light-Duty Vehicles, Truck, Ships and Airplanes, in: Stolten, D.: Hydrogen and Fuel Cells 2010, Weinheim.