Dosing pumps - revisited

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Abstract

Initially used for auxiliary parking heaters for mobile automotive systems, the range of applications for electromagnetically driven dosing pumps has been widely enlarged during the past few years. Whereas originally only diesel fuel had to be delivered, nowadays all kinds of liquid media have to be pumped. These, diesel and petrol fuels and a lot of additives, require verification and improvement of the design for optimal usage and low energy consumption. Thus, the dosing pump has been improved to efficiently 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 fluid is required.

This contribution is concerned with the principal design of such pumps, functioning, potential of accuracy and lastly with some specific features (valve function, dry run behaviour and self-priming potential) as well as the potential for optimization (installation space, part reduction).

KEYWORDS: metering, dosing, pump, fuel, biofuels

1. Introduction

The innovative type of a dosing unit combines the functions 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 integration of functions leads to less complex, more robust systems. Investigations into potential hydraulic system lay-outs show that 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.

As the dosing pumps presented are able to pump a defined, small volume per stroke, the total flow rate is determined by the frequency of the piston's movement only, which is the basis for easy control. Exact dosing is achieved by the geometry of the construction only. Hence, 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 of both principles: constant flow and precise metering within a range up to 8l/h with a precision of 0,5%. This new design is based on a novel approach, or by the use of integrated attenuators. Tests are made to check potential influence factors, as counter pressure, temperature etc.

Dosing units have to continually deliver the required amount of liquid media during their lifetime. So, all pump designs were consequently tested in durability tests with different kinds of fuel, even biodiesel-fuels containing aggressive substances, or gasoline-alcohol-blends. The global usage of metering units requires a robust design and robust materials as they are in direct contact with the fluids. Therefore these pumps have to be able to deliver all fuels that are commercially obtainable. Tests have also been made to show that the pumps meet the special demands of biomass fuels that potentially may degenerate. Based on these test results, the interaction of dosing unit and the individual future fuels is taken into account.

2. Historical survey

For more than 25 years now, integrated piston-pumps for dosing fuel have been developed and manufactured in serial production. Within the field of precise metering of fuels, Thomas set significant milestones in these last 25 years. Before that time, the pumps consisted of two separate functional parts, namely an electro-magnetically driven actuator and the pump. Thomas started with the development and production of the first actuator and expanded the scope of delivery starting in the mid-80s with the model "DP2" as first united electro-magnetically driven dosing pump. Since the second half of the 1980s, the "DP2" is in serial production as shown in fig. 1.

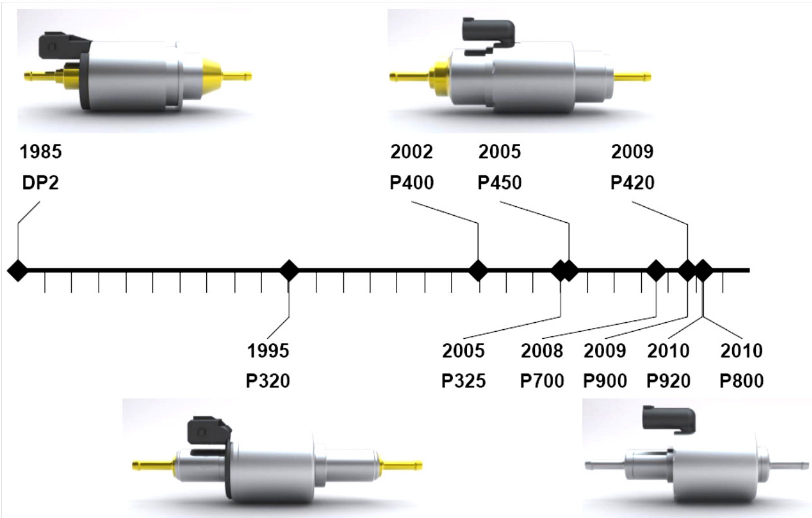

Figure 1: Milestones in the development of Thomas Metering Pumps

By using the innovative “P400”, modern fuel operated auxiliary heating systems can get the fuel needed in a pulsation-free manner. The “P400”, in serial production since 2002, is ideally suitable for systems needing constant fuel flow without pressure pulsation, e. g. heaters based on the venturi principle, see /1/. By using a specially dedicated concept of pump and actuator, the design is accentuated to this intention by reducing the stroke volume and by the integration of an attenuator. Thus, the remaining pressure pulses are reduced so that they are not noticeable by the system. For challenging applications, the “P450” assures these qualities over a wide range of temperatures, even with very low temperatures.

A second type series was initiated by Thomas in the early 1990s by developing the “P320” for heaters operated with diesel fuels, initially used for truck applications mainly. In serial production since 1995, this original field of application was expanded and the “P320” soon became a basic dosing pump for several fields of application. This type is characterized by the robust design that simplifies the structure. Exceeding the ordinary arrangements for proliferation of serial products, the spectrum of power was extended significantly without enlarging the outer dimensions. Based on this, the maximum flow of the “P325” is more than doubled compared to the “P320”. The “P900” is a serial pump, specifically developed for aggressive and potential future fuels.

Based on this knowledge, these types of dosing pumps are used for other applications. Prior to the year 2000, the use of the metering pumps using the 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 include: priming, suction, delivering, dosing/metering, e. g. They enlarged the range of applications and enabled the optimization of existent facilities. Thanks to these attributes, the compact dosing unit make complex, pressure-controlled metering systems superfluous. 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 at high costs, are not necessarily needed. Thus, the total amount of electric and hydraulic interfaces can be reduced to the minimum. This will lead to significantly reduced total weight, installation space and total costs.

3. Potential for technical optimization

Opportunities compete with risks if a well established and reliable product has to be optimized. In order to improve the known advantages and to apply state-of-the-art design-principles, the abilities of the compact dosing units have been significantly enlarged. Hence, new potential applications are explored. The main focus of the development of the “P320” was laid on functionality within the customer’s system. As one consequence, the specifications of the required metering pump for auxiliary heaters had to be standardized and to be brought into a reliable dosing unit. As described above, the “P320” has proved its qualities on the market for nearly two decades now: Up to now, approx. millions of units have been produced and they are acting flawlessly with all applications.

Sporer et al. /2/ published their investigations into a comparable design principle by nominating it as “1st Design” representing the well-established series design being characterized by only positive experiences in the field applications. Based on the experiences of the ”1st Design”, an optimized “2nd Design” was developed. The ”1st Design” was developed with inherent safeness addition, due to parallel development paths and the system environment that was not deeply understood during the phase of development.

Incorporating the confirmed technical status, i. e. the blameless series experience over more than three decades now, broad opportunities for optimization can be seen. Herein, the potential can be used for establishing the recent status or – preferably – for significant enlargement of the technical limits. Challenging complex solutions should be regarded as a consequent extrapolating of the intention to develop and produce an optimized product, exploiting the incorporated reserves without risk by considerate approach to the application and production limitations.

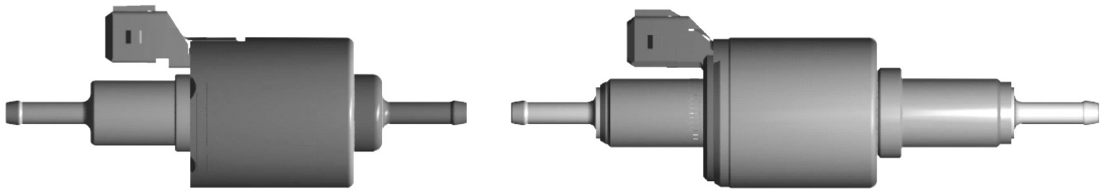

Figure 2: “P920” (on the left) compared to the “P320”

A paradigm par excellence for this approach is given by the development of the ”P920”. Evolving from the “1st Design” of the well-tried “P320”, the upcoming ”P920”, see fig. 2, is a dosing unit that outperforms the “P320”. The advantages are obvious, as e. g. 40 % less single parts are needed. As before the “P320”, the „P920” also will stand the test within series applications. To follow the strategy of conserving resources, with the ”P920”, the very compact design of the “P320” was reduced to the minimum possible for the defined range of power. But this “2nd Design” leads to a reduction of mass of about 20 %. Further advantages are given with doubled corrosion resistance and improved suction ability.

4. Introduction to compact dosing units

Auxiliary power units [APU] using fuel cells mostly need fuels in a special condition. Liquid hydrocarbons have to be converted into gas mixture containing hydrogen, see /6/. This conversion is performed by means of a reformer. This is a challenge especially for mobile APUs. According to /4/, these systems may use Solid Oxide Fuel Cell [SOFC] technology. They are advantageous as they allow engine-independent allocation of electric energy. Trucks, aircrafts, ships and cars usually have liquid fuels, diesel e. g., aboard which have to be reformed before entering the fuel cell, see /7/.

Metering pumps as described above are such integrated, compact units combining several functions. 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. Also, a filter can be integrated. Thus, taking into account these characteristics, compact dosing units are suitable for delivering different fuels to the reformer of stationary or mobile fuel cell applications in a very precise manner.

Especially in the field of exhaust gas after-treatment, the dosing units based on the “P320” are beneficial to new challenging use within clean technology. Being more or less independent of the engine management system and the operation condition, the particle filter, e. g., can be regenerated by metering an additive into the fuel tank. A second possibility is the regeneration by injecting diesel fuel vapour into the exhaust directly. For this purpose, an exact amount of diesel fuel is vapourized by means of a thermal reactor or a vapourizer. This small additional amount of fuel sees to it that the light-off temperature of the embedded soot can be achieved using the diesel oxidation catalyst.

Thomas offers a highly integrated solution for procuring the fuel needed. Namely: the exact amount necessary for the chemical reaction is delivered. Within the described application, it is important not to exceed the amount as otherwise unburned fuel would come into the exhaust. The dosing unit is not only metering the amount of fuel precisely, but is also able to deliver fuel with the operating pressure needed. All available fuels on the global market are able to be pumped without constraints. A wide range of operation is covered with the dosing unit which is a very safe system. Integrated safety features like shut-off valves stop undesired fuel flow.

5. Mode of operation

The metering unit is essentially solenoid driven actuator. Fig. 3 shows the actuator in a sectional view in the not energized, i. e. normal position. Actuated by the solenoid, the pump's piston is alternatingly loaded axially in the pump's cylinder from the one end position to the other. The fluid is drawn into the pump through the filter past the sealing element. This sealing element is one of the safety features as it prevents fluid from flowing backwards in the case of a not-energized passive state of the metering unit.

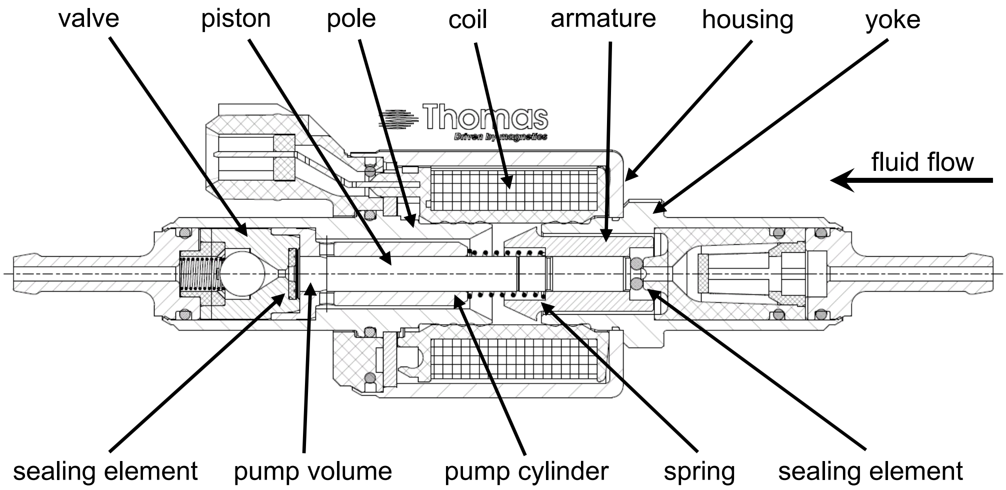

Figure 3: "P320" sectional view, non-energized, normal position shown

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. This emission is effected by the movement of the piston of the pump in axial direction. 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, a magnetic field is established and a ferromagnetic circuit is setup through the housing, yoke, armature and pole, see /3/. As the magnetic field tries to close the air gap between the pole and the armature, the slidable armature is moved in axial direction. Fig. 3 shows this air gap with the cone-shaped geometry. Starting from the normal position, which is shown in fig. 3, the armature and piston move axially as an assembly. After switching off the voltage, the armature and the piston are returned by the spring and reach the normal end position again. By applying the electric signal, the axial movement of the piston leads to an increasing pressure in the pump volume. Hence, the fluid in that chamber unseats the ball and flows through the check valves. At the conclusion of pumping action, the ball reseats and suction begins to develop as the spring returns the piston. Once the returning piston passes the cross hole, further fluid can stream into that volume. With each electric pulse, this process is repeated. 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.

For special applications, an inverse functional principle is applied which is shown in fig. 4. The metering unit is essentially solenoid driven actuator. In fig. 4 the actuator is also shown in a sectional view in normal position, i. e. not energized. Actuated by the solenoid, the pump's piston is alternatingly loaded axially in the pump's cylinder from the one end position to the other. By applying the electrical signal, the piston creates suction in the pump displacement area. As the fluid passes the cross hole, the pump volume is filled with further fluid coming from the inlet side of the pump. By switching off the electrical signal, the spring moves the armature and the piston back to the not energized normal position. During this movement, the fluid inside the pump volume is forced to stream through the outlet valve.

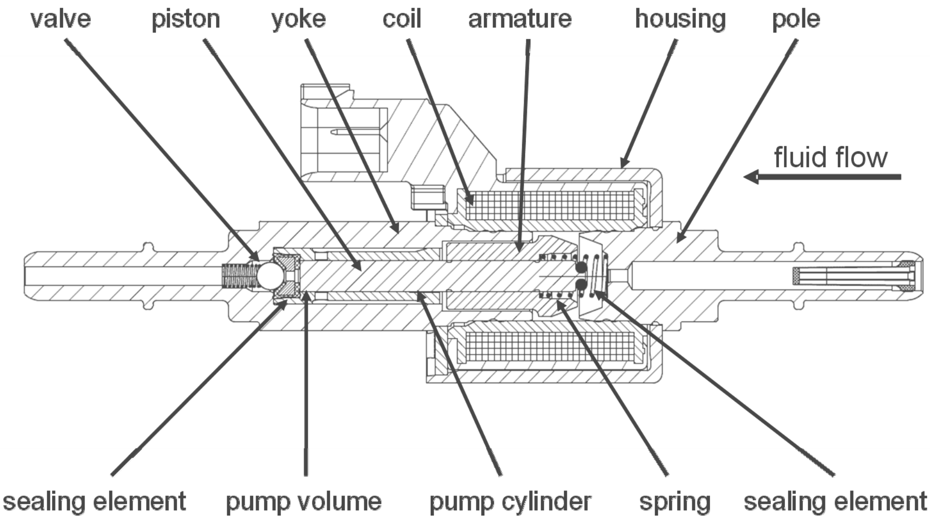

Figure 4: "P900" sectional view, non-energized, normal position shown

The advantage of the functional principle of the pump type "P900" lies in the sealing. No unwanted flow will occur because the pump's piston itself is pushed by the spring onto the valve seat. This effect is even intensified if the pressure level at the inlet port is increased. And, a further advantage in the noise emission is approximately independent of the pump control.

6. Repeatability investigations

The average flow rate of several single shots is for a large number of applications more relevant than the consideration of one single shot. Measurements of the pumps for comparing the accuracy are performed in order to describe the characteristic of the pump. The test medium used for this experiment was ARAL 4005. This fluid is a not-flammable surrogate liquid based on hydrocarbon. The test was performed with two different kinds of piston pumps. The test conditions for the measurement of these pumps are exactly the same, namely the ambient and fluid temperature, the control values, the test setup and the measurement equipment.

On the scale, a beaker was situated, containing the fluid which was delivered. This beaker was connected by a hose with the pump. The inside-diameter of the hose was 4 mm and the length 1,400 mm. At the outlet of the pump, a comparable hose with the same inside-diameter was adapted. This hose ends at a separate canister being exposed to the normal pressure of the atmosphere. The pump was placed 600 mm above the beaker. By energizing the pump, the medium was drawn from the beaker through the pump to the canister. The removed medium leads to a reduction in weight. This reduction defined the delivered volume. The operation parameters of the pump could be modified in certain ranges. The described measurements were performed with a voltage of 12 V in the case of P900 and 8 V in the case of P920M, a switch-on-time of 25 ms (time sequence for one stroke of the piston), a clock pulse frequency of 10 Hz and a pressure level of 0 bar. The pump was actuated for 100 shots and the mass difference before starting the pump and after 100 shots was evaluated. In fig. 5, the measurement results for the different pump types are shown. In table 1, the results of the different pump designs regarding the averaged flow rate and its standard deviation are compared.

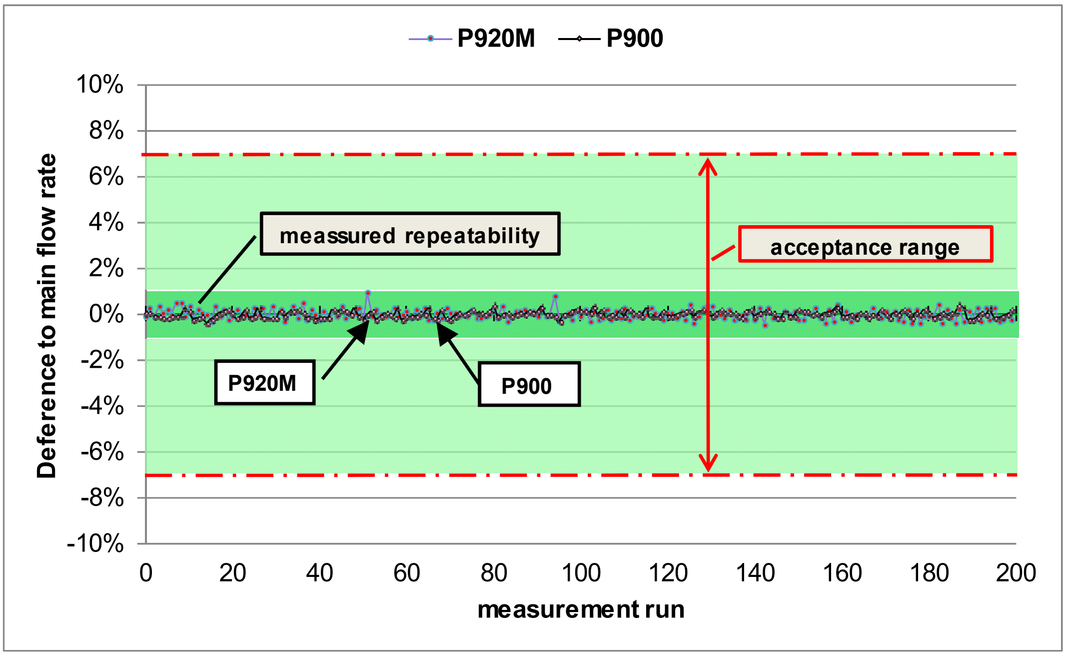

Figure 5: Accuracy of the averaged flow rate [200 measurement runs, 100 shots each]

These results clearly show the average flow rate. The precision of both pumps is in an outstanding range of about ±0.5 % of the mean. Independently, the “P900” and the “P920” each have a standard deviation of less than 0.25 %. In field applications, the results of this excellent level described in table 1 should be considered for the layout of the corresponding system.

	delivered volume per stroke mean value over 200 measurements (100 shots per measurement)	over all standard deviation (relative to the mean value)
P900	50.2 mm³	0.075 mm³ (0.15 %)
P920 M	22.6 mm³	0.052 mm³ (0.23 %)

Table 1: Accuracy of the “averaged flow rate”

7. Accurate dosing behaviour over lifetime

Dosing units have to guarantee the accuracy of dosing during their lifetime. The current discussion of launching ethanol blends, like E10 takes place in Europe and other parts of the world. Therefore, in fact, dosing units have to deliver the precise dosing during their lifetime. Hence, all pump designs were consequently tested by performing durability tests with different kinds of fuel according to automotive standards, see /5/, even biodiesel-fuels and bioethanol-fuel blends containing aggressive substances. For example, the pump type "P320" ran in a durability test with ULSD (ultra low sulphur diesel) for a period time of more than 13,500 hours, actuated with a high frequency of 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. This is an excellent result indeed! After dismantling the pumps and inspecting the single parts, every single part appeared like new, only minimal traces of use were recognizable. The global usage of metering units of that type requires a robust design and robust materials as they are in direct contact to the fluid. Well known for robustness, all 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 fulfill special demands for biomass fuels that potentially may degenerate. For that intention, special test fuels have been defined by, e. g. the SAE J1681, and are 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 be composed especially for these investigations.

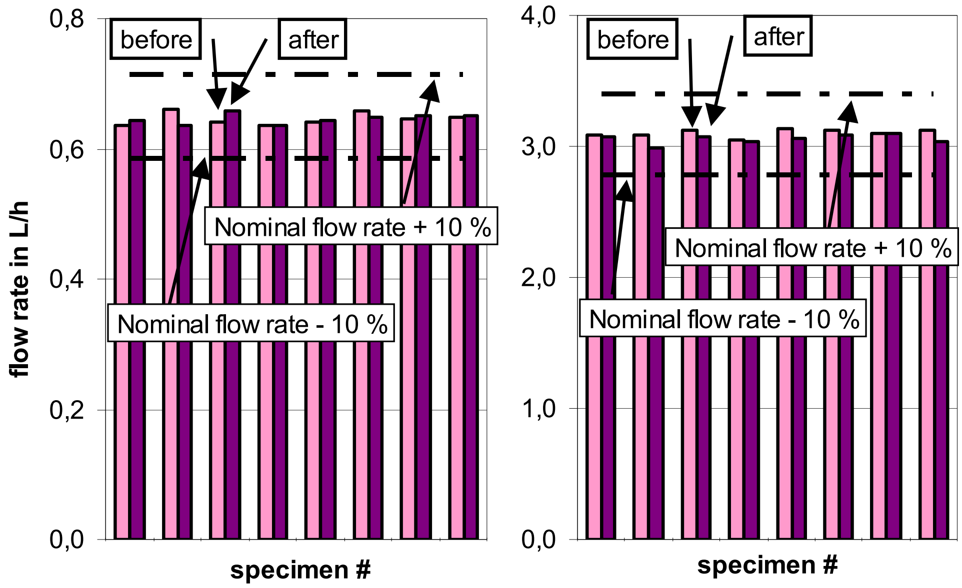

Figure 6: Durability test; E22 (left, "P920"); aggressive biodiesel B20 (right, "P900")

Two different kinds of durability tests were performed with the pump types "P900", see /8/, and the type "P920": a durability test with aggressive diesel containing 20 % FAME and a durability test with an aggressive gasoline blend containing 22 % bio-ethanol, results: see fig. 6. The test with diesel was performed at a temperature of $T_{Fluid} = T_{amb} >> 50$ °C (323,15 K), and the test with E22 was performed at ambient temperature. Thus, both temperatures representing real worst case conditions for service. The duration was for each test 1,000 hours with a driving clock frequency of 17 Hz. In fig. 6, the measured flow rate is shown before the start of the durability test and at the end of the test, i. e. after 1,000 hours or 61 million cycles. The deviation of the measured flow rate after the test was insignificant. All single parts of the pumps did not show any significant wear and have been found comparable to an unused condition. Thus, giving a résumé, the compact Thomas dosing units are robust against all fuels currently obtainable on the market world-wide.

8. Dry run behaviour

Under certain circumstances, the fuel supply to the dosing pump can temporarily be interrupted. For example, if a fuel hose has to be exchanged during service. In order to simulate such an unforeseen operation in a realistic manner, a dry running test has to be carried out. If the component was driven with bio-fuel-blends before, the remaining fuel in the pump may alter chemically. This is due to the materials used with surfaces in direct contact to the fuel. Copper and zinc are well-known for accelerating these effects, for details see /9/, resp. SAE J1681, e. g. The Thomas "P900"-family of pumps therefore use stainless steels or likewise uncritical materials to prevent the fuel from being degenerated due to the impact of the materials in direct contact to such aggressive fuels. It should be noted that the robust design of dosing units using inert surfaces leads to the observation that neither the function of the pump and nor the accuracy of the delivered flow rate is affected by dry running.

9. Concluding remarks

The in-line dosing units presented show excellent precision in metering and robustness in delivering even aggressive bio-fuels. This precision and robustness is nearly independent of the fluid and is guarantied for lifetime. This outstanding dosing capability is based on the geometric displacement exactly defined and available for the complete clock frequency range.

Many applications need compact dosing units that meter fuel very accurately. Investigations into this showed a precision of considerably less than 1 % deviation to the mean flow. 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 lifetime as well. 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. For the use within fuel cell systems and especially for the fuel delivery into reformers, Thomas metering pumps offer an integrated solution.

10. References

/1/ Nothen, M.: Einblick in die neue Brenner-Technologie des Webasto Zu- und Standheizers Thermo Top V in: Schlenz, D.: PKW-Klimatisierung III 2004.

/2/ Sporer et al.: Automobil-Produktion Feb. 2009, S. 24f.

/3/ Kallenbach, E. et al.: Elektromagnete ^{III}2008, Wiesbaden.

/4/ 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.

/5/ Müller, A. et al.: Dosierpumpen: Neue Potentiale im Spannungsfeld zwischen Komfort und weltweiter Standardisierung, in: Hofhaus, J. (Ed.): PKW-Klimatisierung VI, 2010, pp. 174.

/6/ Hansen, J.: Fuels and Fuel Processing Options for Fuel Cells, in: Fuel Cell World Proceedings 2004, pp. 325.

/7/ Hartmann, L. et al.: Partial Oxidation of Diesel – Procedural Problems and Solutions, in Proceedings of 6th European Solid Oxide Fuel Cell Forum 2004, pp. 440.

/8/ Müller, A, et al.: On Dosing Units Suitable for Fuel Cell Applications, in Proceedings of 9th European Solid Oxide Fuel Cell Forum 2010.

/9/ Lechner-Knoblauch, U. et al.: Corrosion of Zinc, Copper and Iron in contaminated non-aqueous alcohols, in Electrochimica acta, Vol. 32, No. 6, pp. 901-907, 1987.