CONSEIL INTERNATIONAL
DES MACHINES A COMBUSTION

INTERNATIONAL COUNCIL
ON COMBUSTION ENGINES

PAPER NO.: 131

Economical and technical aspects of DUAP's fuel Injection parts and systems

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Abstract: Today the user of an large bore engine is confronted with two major challenges: on one hand are the increasing fuel costs which are due to the volatility of the crude oil price hard to predict, on the other hand are the step-by-step more stringent international emission levels. The fuel costs are the major part of the total operational costs of a large bore engine – no matter if marine use or land based.

Furthermore, there are not many alternatives to IC engines for main propulsion or power generation onboard of a vessel.

Luckily, the engine for itself is sturdy and reliable; some engines are well over 30 years old and still good for another one or two decades. But how to keep up with the two major challenges?

As far as the fuel injection system is concerned, DUAP does have solutions. Without design changes on the fuel injection system, which would require a lot of work to renew the classification tests, DUAP can provide out of the DUATOP product line nozzles and pump elements for a large variety of engines. These parts are manufactured at our site in Switzerland to the highest level of quality standards and workmanship. What is the benefit for the user? Simply spoken, saving costs. Fuel consumption can be decreased and the TBO can be extended. The following article will provide the technical background.

Beside the DUATOP spare parts, DUAP also provides complete Common Rail fuel injection systems, including the newest Electronic Engine Control Unit. Like the DUATOP spare parts, they are also produced in Switzerland. Due to the wide product range of High Pressures Pumps, Fuel Rails, Injectors and Sensors, a large variety of engines from approx. 500kW to 12MW can be equipped. Of course this benefits are also for new built engines and their manufacturer available.

Additionally to the fuel injection parts for MDO, MGO and HFO DUAP also provides special components for Gas Engines, comprising complete Micro Pilot DUARAIL Systems as well as Pre-Chambers, Check Valves and Gas Injectors. Although gas engines are more niche products than mainstream, their spread will expand due to good emission levels and moderate fuel costs.

The intention of this paper is to demonstrate the benefits DUARAIL and DUATOP FIE parts can provide to engine OEM's and end-users. Their technical features and new engineering results in numerical simulation like FEM or hydraulic simulation and extensive testing in DUAP's own test facility as well as aspect regarding components for gas engines are included.

INTRODUCTION

Founded 1943 in Herzogenbuchsee, Switzerland, DUAP develops and manufactures fuel injection components from spare parts for existing engines to complete Common-Rail systems, especially for large bore engines (bore > 200 mm).

Beside the main business with large engines, we apply our knowledge also to other areas, such as motor sport and aerospace applications, where highest quality is demanded.

Customers from various other industries count on the skills and experience of DUAP in the areas of heat treatment and hard machining whenever high degree of precision is required.

The following paper gives a short overview of all current activities of DUAP which include the manufacturing of spare parts for existing engines, the development, testing of complete new Common-Rail systems developed by DUAP for customers worldwide.

SPARE PARTS (DUATOP)

With the DUATOP product line, introduced in 1999, DUAP offers its customers spare parts for existing fuel injection systems.

Today, we are able to deliver spare nozzles for about 70 different types of engines from our stock. In addition, we have also other spare parts such as plunger/barrel and other wear parts for conventional fuel injection systems. All DUATOP products have in common that they are highly appreciated as spare parts by the customers for their reliability and longlivity.

Figure 1 - Various nozzles from the DUATOP product line

Due to cooperation with the major classification societies, i.e. Germanischer Lloyd, a major share of the DUATOP nozzles can be certified to the IMO MARPOL 73/78 Annex VI standard.

Beside the DUATOP line, DUAP also has long standing contracts for the manufacturing of fuel injection equipment for well-known engine manufacturers that distribute these spare parts under their own name as OEM spares.

<u>DUATOP nozzle for SULZER ZA40S</u>

The Sulzer ZA40S four-stroke engine entered service in 1985 as a successor of the Sulzer Z40 type. Following the takeover of New Sulzer Diesel by Wärtsilä, the production of the engine continued. Today several hundred engines are in worldwide use.

In the last ten years, DUAP has produced over 42'300 nozzles as spare parts for the Sulzer ZA40S engine. Depending on the particular application of the engine (power generation, marine main propulsion), the nozzle is currently available in six different versions, where the number of spray holes and the spray pattern are slightly different.

<u>Design features of DUATOP nozzles</u>

The rough environment and inferior fuel qualities to which the nozzles are exposed to (inferior fuel quality such as abrasive residues or an increased tendency to soot production) demands for exceptionally solutions for design and manufacturing.

Despite the existing ISO 8217 standard that defines maximum tolerance limits for water contamination or Micro Carbon Residue (MCR), these limits can sometimes be exceeded depending on the origin of the Heavy Fuel Oil.

Our particular focus is on the right choice of the basic materials and on accordant processing, especially for all heat treatment operations.

As a result of more than 60 years of experience in design and manufacturing of FIE all DUAP nozzles, no matter if DUATOP or OEM, have a considerably increased lifespan compared to the nozzles from our competitors.

An increased lifetime does not only mean a longer TBO and less standstill for maintenance, due to the reduced wear of the spray holes, the overall fuel consumption decreases up to 1 %.

Manufacturing of FIE

With the existing production facilities at our site in Herzogenbuchsee, which include a complete heat treatment shop and a material analysis lab, DUAP is able to conduct all necessary process steps in-house. This allows a complete quality control from soft machining over heat treatment to hard machining.

Figure 2 – Tempering furnace in heat treatment shop at DUAP site in Herzogenbuchsee

As a result of our long lasting experience in heat treatment, DUAP is able to apply the most adequate procedure for every component of the injection system.

Figure 3 - Cylindrical grinding machine with robot arm for automatised feeding of workpieces

Though the fact that the lots produced at DUAP site are rather small compared to an automobile supplier, automatised production is not unknown to us. In the recent years, we have successfully commissioned full automatised machining centers.

MICRO PILOT IGNITION (MPI)

Beside spare parts for the large diesel engines, DUAP has also a broad experience with Micro-Pilot Ignition (MPI) as an alternative for the conventional Spark-Ignition (SI) for gas or dual fuel engines. Since the first MPI-system was successfully commissioned at customer site in 2001, DUAP has designed and manufactured different MPI-systems for engines worldwide.

A micro-pilot system can be used for open chamber (OC) as well as for pre-chamber (PCC) engines.

Our greatest success in the area of MPI was the cooperation with Mitsubishi Heavy Industries [3] for the development of the injection system for the MACH-30G engine. Until today 150 engines (mainly used for power generation) were sold equipped with a MPI-CR-system from DUAP to the end customer.

The advantages of a Micro-Pilot Ignition (MPI) compared to a Spark-Ignition (SI) engine are as follows [1]:

- Considerably increased maintenance interval – an MPI engine has an average TBO of 4’000 to 8’000 hours compared to 1’000 to 2’000 hours of TBO of a SI engine. This does not only reduce the costs for spare parts, it also reduces the standstill of the engine due to maintenance.
- Less susceptible to fluctuations of the gas mixture – The energy of the pilot fuel is

approximately 8'000 times as high as the electrical energy of a spark plug. Therefore a MPI engine is able to ignite a leaner mixture without an additional gas supply to the pre-chamber.

- Increased stability of ignition and combustion – a stable ignition of a SI engine requires a stable mixture in the pre-chamber. Cyclic variations of the mixture distribution in the pre-chamber make it difficult to achieve a stable and robust ignition on a SI engine.

- Lower risk of misfire – if the mixture in the pre-chamber is too rich, there is the risk of augmented generation of soot which leads to a locking of the gas check valve of the pre-chamber.

As fuel for the pilot-injection, either Marine Diesel Oil (acc. to ISO 8217 or JIS K 2204) or A-Oil (acc. to JIS K 2205) can be used.

Second Generation of DUARAIL MPI

Encouraged by the success of the first generation, DUAP decided to develop a second generation of the DUARAIL for MPI applications.

The targets for the development were as followed:

- Supply of a complete system, including ECU, all necessary sensors and a full cable harness

- Further reduction of the total costs of ownership for the end customer by an increased TBO of the single components

- Design of components with regard to an easy exchange of the wear parts such as nozzle and control module.

The MPI system of DUAP consists of the following components:

High Pressure Pump

A MPI-CR-system requires considerably lower amounts of liquid fuel than a Full-CR-system. Therefore, DUAP has developed a new generation of R-pumps executed as a modular system. The CRP-12DF-2R (Fig. 4), which represents currently the smallest Common-Rail pump of DUAP (cf. Table 1), was designed with regard to MPI applications.

Figure 4 - Cross section of the DUAP 12-DF-2R pump

Injector

Due to the fact that the injectors are the last link in the chain and are also in quantity the component used most in the complete CR-system, they play a leading role in the development process.

DUAP aims to apply as much standardized components for the design of the injector in order to reduce the cost as well as the required time for the development.

Due to the modular concept of the internal parts of the injector, DUAP is able to adapt the external shape of the injector to the given installation space requirements. A change of the cylinder head is normally not required. This sometimes lead to special executions (Fig. 5), i.e. with extra long shaft.

Figure 5 - Sliced Common-Rail injector for Micro-Pilot applications (in a special version with an extra long shaft)

The MPI-injectors can be overhauled up to 3 times after the TBO is reached. This is either done by DUAP or a licensed partner. The overhaul includes a complete cleaning of the injector, an exchange of all wear parts and a documented re-calibration.

Rail System

As no outer shape of an engine type is similar to an other, the rail as well as all pipes have to be adapted to the particular geometry. As for the injectors, DUAP aims to use as much standardised components as possible.

Depending on the requirements of the particular customer an application, DUAP can apply all safety features of a full-CR such as flow-limiters or double-walled pipes to a MPI-system (Fig. 6).

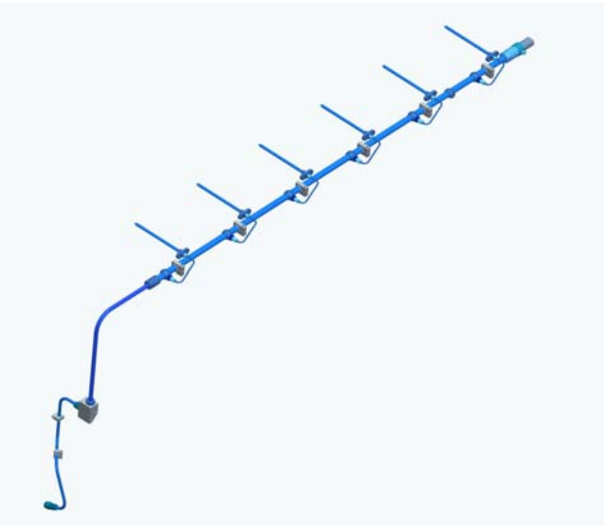

Figure 6 - Rail assembly for a 6L-engine

ECU

With the self-developed DUATRON-ECU (Fig. 7) DUAP is able to provide the customer a complete and optimally tuned Common-Rail system from one single hand.

For the design of the DUATRON-ECU the specific requirements of large-bore engines have been considered, especially the ambient conditions, i.e. temperatures, humidity, presence of oil and fuel, vibrations. This lead to a very rugged design, special attention was paid to the connectors (MIL-DTL 38999).

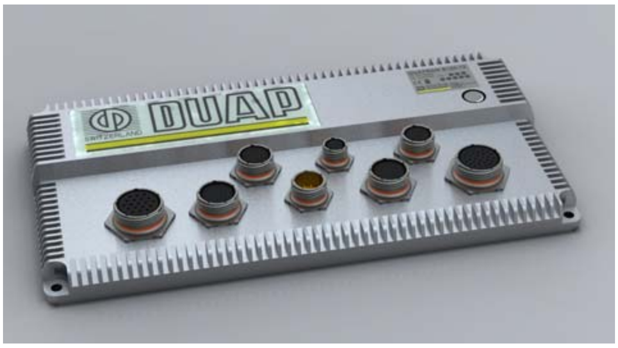

Figure 7 - DUATRON ECU

DUAP also provides all necessary sensors as well as the complete cable harness that fits to the engine as well as all other components.

According to the requirements of the specific application, the DUATRON is also able to control other elements of the engine, for example the turbocharger.

FULL-COMMON-RAIL APPLICATIONS

As all other products of DUAP, the high-pressure pumps are gradually improved. Since the last CIMAC congress in 2007 [2], the product range was once again extended an improved according to the requirements of the customers.

With the development of the new single-cylinder 18HF-1 pump (Fig. 8), DUAP can offer a cost-effective solution for small HFO-engines (range of bore between 180 and 220 mm).

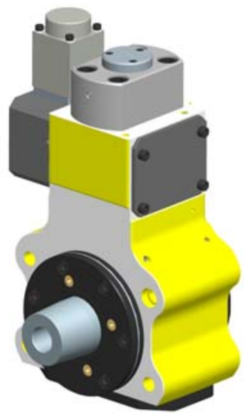

Figure 8 - 3D-CAD model Common Rail Pump (CRP)-18HF-1

Pump Type	Delivery Rate at Rated Speed	max. Engine Power[1] (with one pump)
CRP-12DF-2R	3.5 l/min	800 kW
CRP-12DF-3R	5.2 l/min	1'200 kW
CRP-12DF-5R	8.7 l/min	2'000 kW
CRP-18HF-1	8.9 l/min	2'000 kW
CRP-18HF-2V	17.8 l/min	4'000 kW
CRP-18HF-4V	35.7 l/min	8'000 kW

Table 1 - Overview of Common-Rail Pumps

For redundancy and the increase of the total delivery volume, two or even more pumps can be used for one single engine.

DEVELOPMENT OF COMPONENTS

Highest requirements to the quality of the components also means highest requirements to its particular testing. Therefore all components that leave or site in Herzogenbuchsee have been previously tested according to the required standards.

Testing of HFO components

As already described in the first chapter, the use of Heavy Fuel Oil (HFO) places highest demands to the components.

When it comes to testing of HFO components in a test lab, the difficulty an FIE manufacturer faces are manifold:

- Handling and logistic of HFO in the midland
- High costs due to short lifetime when recycling in a test bench without
- Legislative restrictions

In order to overcome these hurdles, DUAP has developed in cooperation with a renowned oil blender in Switzerland a synthetic oil to simulate temperature and viscosity for tests of FIE components. The target was to use the oil more than 2000 h at a max. temperature of 150 °C without significant changes of the specification.

The resulting product, known as DUAFLUID is a replacement for residual fuels. It allows a realistic simulation of viscosities, lubrication characteristics as well as heat properties that remain constant over the complete service life. It stays also pumpable at room temperature and provides a protection against corrosion for all components.

In order to utilize the properties of DUAFLUID optimally, DUAP procured a testing device (Fig. 9) in addition to the existing testing facilities, especially for all of its heavy fuel equipment (that includes pump, the complete rail assembly and the injectors).

Figure 9 - Equipment for the treatment of the DUAFLUID

The kinematic viscosity according to DIN 51562-1 for different temperature is outlined in Table 2:

Temperature	Kinematic Viscosity
+ 40 °C	390 – 420 mm^2/s
+ 100 °C	36 – 44 mm^2/s
+ 140 °C	13 – 17 mm^2/s

Table 2 - Overview kinematic viscosity DUAFLUID

Numerical Simulation

In order to reduce the required time for the development of the components and to eliminate possible sources of error as early as possible in the development process, DUAP uses (besides the extensive physical testing of the components mentioned in the previous chapter) a great variety of simulation software, including HydSim and ANSYS Workbench.

[1] The maximum possible engine power is calculated with an assumed fuel consumption of 190 g/kWh for operations with MDO.

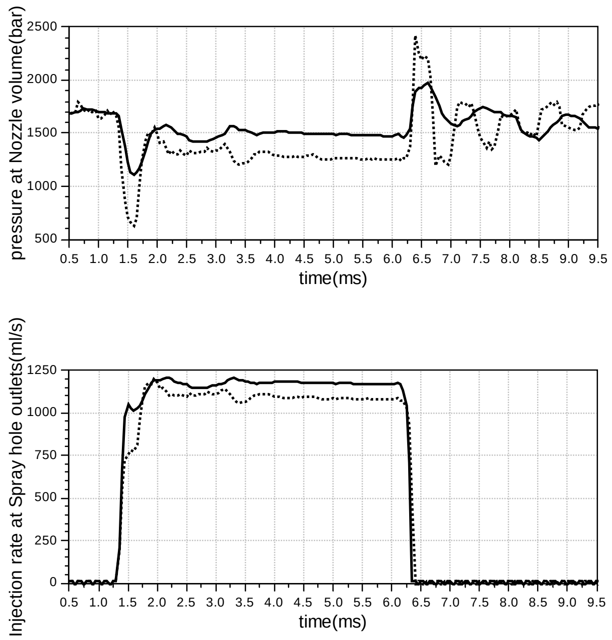

Figure 10 – Results of an optimized nozzle using Hydsim

In the example shown in Fig. 10, HydSim was used to optimize the high-pressure volumes inside of a nozzle. The upper diagram represents the pressure inside the nozzle chamber and the lower diagram the injection rate. The dotted line is before and the solid line is after the simulation.

Due to the use of numerical simulation, the time necessary for the development as well as the costs can be decreased tremendously. Another example of numerical simulation is the use of finite element analysis (FEA), shown in Fig. 11.

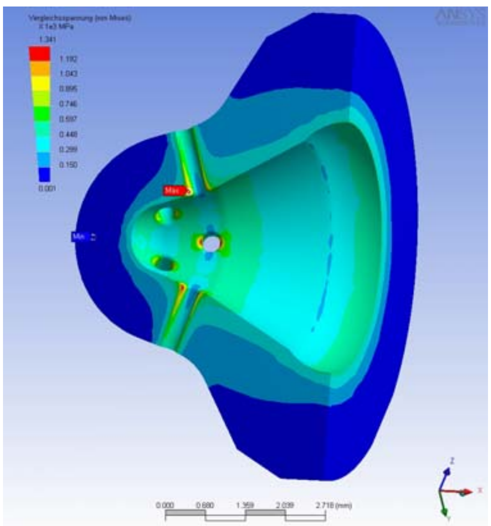

Figure 11 – FEA of a nozzle tip

For special applications such as electromagnetic simulations (as visible in Fig. 12) or computational fluid dynamic simulation (CFD), DUAP cooperates with leading companies in their fields in order to achieve optimal results.

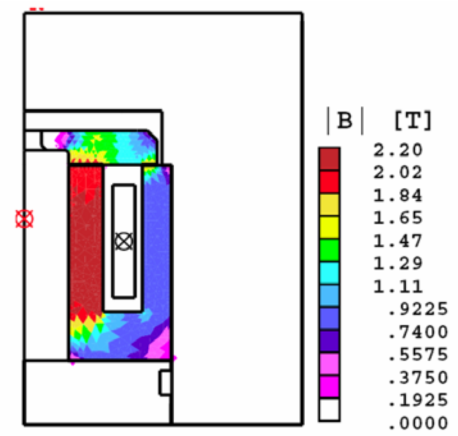

Figure 12 - Simulation of electromagnetic induction of a DUAP-solenoid (in cooperation with Drivetek AG)

CONCLUSIONS

DUAP is able to provide a variety of different FIE-components of existing engines. The DUATOP spare parts are highly appreciated by the customers for its quality and longevity.

The high vertical integration of our manufacturing site in Herzogenbuchsee, a general view over all critical operations can be assured at any given time. A quality assurance system according to the ISO 9001 standard ensures that errors can be identified and eliminated. Furthermore it provides a continuous improvement of all internal processes.

In the future, DUAP will increasingly focus on the development of complete Common-Rail-systems, including also the Electronic Control Unit with all necessary sensors and the complete cable harness.

For the development of new components, DUAP uses beside a full 3D-CAD system various CAE software in order to reduce the development time of the components.

With state-of-the-art testing facilities, a comprehensive testing of all components can be provided at our site. If required, DUAP tries to find new approaches like the development of the DUAFLUID as a substitute for HFO-testing.

NOMENCLATURE

BMEP	Break Mean Effective Pressure
CAD	Computer Aided Design
CAE	Computer Aided Engineering
CFD	Computational Fluid Dynamics
CR	Common Rail
CRP	Common Rail Pump
ECU	Electronic Control Unit
FEA	Finite Element Analysis
FIE	Fuel Injection Equipment
HFO	Heavy Fuel Oil
ISO	International Organization for Standardization
JIS	Japan Industrial Standard
MCR	Micro Carbon Residue
MDO	Marine Diesel Oil
MPI	Micro Pilot Ignition
OC	Open Chamber
OEM	Original Equipment Manufacturer
PCC	Pre-Combustion Chamber
SI	Spark Ignition
TBO	Time between Overhaul
TCO	Total Cost of Ownership

ACKNOWLEDGEMENTS

The authors would like to thank all employees of DUAP who have contributed their knowledge and experience to this paper. Without their help, it would not have been possible to compile all the items listed.

Furthermore, DUAP would like to express its gratitude to all customers and suppliers for their long-standing support that enables us to achieve our ambitious goals.

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