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DEVELOPMENT AND TEST RESULTS OF A CRYOGENIC HIGH-PRESSURE FUEL GAS SYSTEM

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ABSTRACT

The MethQuest research project is about creating new processes for generating renewable gas fuels and progressing existing technologies. The MethMare group is working on propulsion systems for ships using these fuels. A very promising marine gas engine concept is the direct injection of methane with a small amount of diesel for ignition whereby unwanted methane slip remains negligible. Therefore a cryogenic high pressure fuel gas system with safe and high dynamic system performance is needed.

At the ILK in Dresden, a container-based test bench has been designed and built to emulate the methane gas system with nitrogen at a pressure of more than 400 bar, a mass flow of up 500 kg/h and the needed high dynamics in pressure and mass-flow load. The performance of the system, including a cryogenic high-pressure pump and a special double tube safety heat exchanger have been investigated. The measurement results are shown and compared with simulation data for the system setup. An outlook to future prediction of system behaviour and application is given.

Keywords: cryogenic high pressure pump, heat exchanger, methane, LIN, LNG

1. INTRODUCTION

LNG and preferably methane generated from renewable energies are considered as clean fuel of the future for ship engines as they have less emissions (carbon dioxide, nitrous oxide, sulphur oxide, particles) than other common marine fuels. On the other hand unburned methane escaping to atmosphere reduces the climate advantage and can even cause more greenhouse gas emissions dependent on engine (Pavlenko et al. 2020). Boog et al. (2019) developed a concept for flexible, direct injecting engines for ship propulsion based on High Pressure Direct Injection (HPDI) with promising potential to minimize methane slip. They identified the high pressure supply system among other things, especially the absence of a suitable heat exchanger and lacking gas supply during high dynamic engine operation, as important basis. This paper shows the design and setup of a high pressure and high dynamic gas supply system. The exemplary experimental result of carrying out an operational profile of a tugboat is shown and evaluated.

2. EXPERIMENTAL SETUP

2.1. Design of high pressure fuel gas system

A system demonstrator of a high pressure fuel gas system operating with liquid nitrogen has been designed and built. Fig. 1 shows the PID and main components of the system. The demonstrator beside the LIN tank is installed in a 20 ft-Container to protect the demonstrator against weather and admittance. The maximum operating pressure of the system is 420 bar. Liquid nitrogen coming from a cryogenic tank (a) is compressed up to 420 bar in a cryogenic high pressure pump (b) and transferred to a special double tube safety heat exchanger (c). After heating to roughly ambient temperatures the nitrogen is throttled by the main process valve (d) and leaves the experiment. The main process valve is a pneumatically driven control valve and simulates the injector valves of the gas engines. Heating medium is a mixture of glycol and water that is heated in an external temperature control unit. The mass flow of glycol can be regulated between 0 and 12.000 kg/h and heated up to 90 °C.

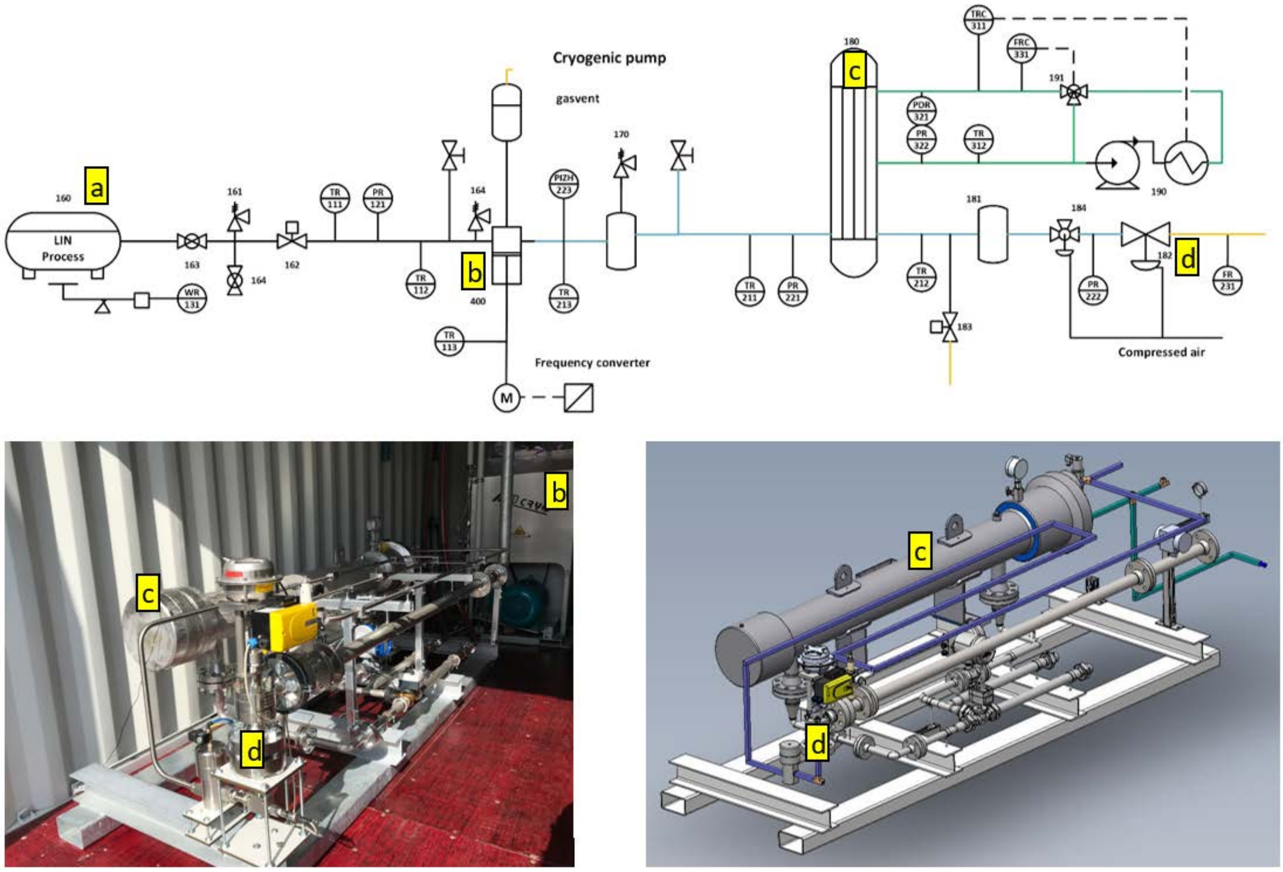

Figure 1: PID, 3D model and built system with the main components: a – LIN Tank, b – cryogenic high pressure pump, c – double tube safety heat exchanger, d – main process valve

2.2. Liquid nitrogen Storage tank

The fuel gas system is fed with liquid nitrogen taken from a storage tank with 600 l capacity. This tank provides liquid nitrogen with a maximum pressure up to 25 bar. The supply pressure can be adjusted by an internal pressure regulator. Before starting the experiments it is necessary to raise the pressure in the tank starting from about ambient pressure to 5 bar. As liquid nitrogen is taken from the bottom of the tank this ensures an adequate subcooling of the liquid nitrogen at the inlet of the high pressure pump and normal operation of the gas vent. Lower tank pressure would possibly result in instable operation of the cryogenic high pressure pump, caused by cavitation. At maximum pump speed the liquid nitrogen capacity lasts for 1 hour system operation. The amount of withdrawn liquid nitrogen is measured by the weight of the storage tank.

2.3. Cryogenic high pressure pump

The projected development of a cryogenic high pressure pump with maximum operating pressure up to 600 bar and special sealing concept to minimize leakage is still under progress. Preliminary sealing tests in liquid nitrogen and pressures of up to 400 bar have shown very promising results.

To perform the experimental investigation on dynamic behaviour of the high pressure fuel system another cryogenic high pressure piston pump is used. The technical data of this pump type is given in Tab.1.

Table 1: Technical data of cryogenic pump from ACD CRYO type P2K 1.25” x 1,5”

Description	Value
operating pressure	420 bar
pump speed	137 – 411 revolutions per minute
flow rate	3.2 – 9.7 litres per minute
motor power	15 kW

This high pressure reciprocating pump is a vertically mounted sump pump. The cold end is submerged inside a large liquid volume where the vacuum jacketed sump acts as a phase separator. A gas vent at the pipe leaving the top end of the sump ensures the existence of liquid nitrogen in the sump at any time. Pump speed can be regulated by a frequency converter.

2.4. Double tube safety heat exchanger

An innovative double tube safety heat exchanger has been developed by Kelvion. The tubes in double tube safety heat exchangers have two walls, consisting of an inner and outer tube. If a tube wall is damaged, the product flows through leakage channels arranged between the double tubes into a leakage collection space and triggers an alarm in the leak detection device. Because the second tube wall remains undamaged, the media are kept separate. Obviously this type of heat exchanger is quite beneficial for the present application as it combines a high safety with a space saving setup.

3. TEST RESULTS

Lots of measurements have been carried out to determine the control of the system. The mass flow of nitrogen is controlled by the valve lift of the main process valve. The pressure is controlled by a frequency converter of the high pressure pump. A simulated transient profile of a tug boat during typical operation (duration: 1 hour) gives time dependent set points to the control. Fig. 3 shows the corresponding data, where red and blue dashed lines are set values for pressure and flow, whereas blue and orange solid lines are measured values of pressure and flow. The purple solid line represent the pump speed between minimum and maximum pump speed in percent. The green solid line is the valve lift where 100 % corresponds to the closed state of the valve. The valve lift is restricted to 90 % to prevent trapped cryogenic liquid in a closed system. Therefore the set values of mass flow lower than about 40 kg/h cannot be reached.

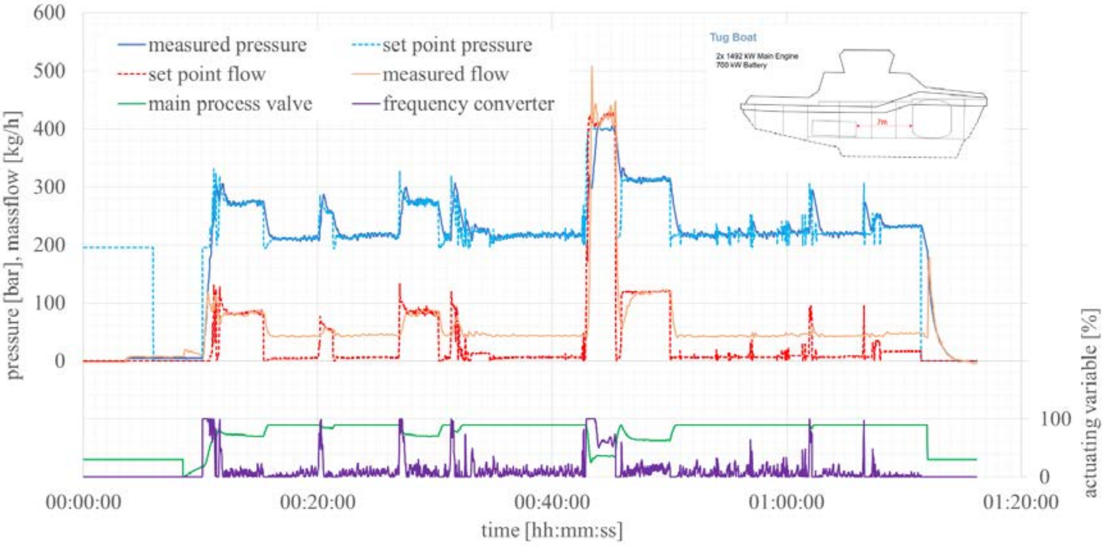

Figure 3: test results of simulated tugboat operation

Further findings and conclusions:

- Because of the high pressure system volume (~10 l) it takes up to several minutes to reduce the system pressure to a new set point in case there is low mass flow exiting the system (idle mode) depending on pressure level. An additional valve could be implemented after the pump to expand high pressure fluid back to the cryogenic tank to speed up the pressure reduction.

- Pressure fluctuations in the system caused by the high pressure pump reached a top value at maximum system pressure and flow (about ± 6 bar)

- Very low mass flow values can only be achieved by intermittent pump operation. This may result in shorter service intervals during long term operation as that is an unfavourable operation mode.

4. CONCLUSIONS

A system demonstrator for a high pressure fuel gas system has been designed and tested with LIN. The experimental results show that high pressure and high dynamic operation can be realized by the cryogenic system. In extensive series of measurements a parameter set for stable operation and system control has been found. System pressure and flow can be controlled almost independently from each other from 0 to 420 bar or respectively from 0 to 500 kg/h respectively.

Future investigations aim towards further optimization of the system operation. From the technological side of view a system demonstrator should be designed for the relevant environment and operation parameters with the medium liquid methane as the next step.

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NOMENCLATURE

LIN	Liquid nitrogen	LNG	Liquid natural gas
PID	Piping and instrumentation diagram		

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