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ENGINE TESTING OF BUS FUELLED WITH LNG

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Abstract

Due to finishing of conventional fossil energy resources, energy security, the desire of independence from imported fuels and reduction of emission of harmful compounds and greenhouse gases in the atmosphere, there is need to explore new technologies using alternative energy sources.

One of alternative energy sources, which can be used in transportation, is natural gas. Natural gas can be use in two forms: as a gas (CNG – Compressed Natural Gas), and as a liquid (LNG - Liquefied Natural Gas). Currently the most often used is CNG fuel. The vehicles, which can be supplied by CNG or LNG fuels are called Natural Gas Vehicles (NGV).

The article presents the basic properties of liquefied natural gas (LNG) used as a fuel for internal combustion engines. There were made the comparison of the characteristics of CNG, LNG and diesel oil as an engine fuels in different aspects. There was presented the measurement method and measurement equipment applied in the Motor Transport Institute, used to measure the fuel consumption of LNG bus in real traffic conditions in comparison to bus, supplied by diesel oil. The results of measurements in SORT tests were presented and compared with fuel consumption of similar buses fuelled with diesel fuel.

Keywords: *LNG, liquefied natural gas, road transport, environmental protection, SORT test*

1. Introduction

Ending of fossil energy sources, conventional fuels prices increase, the energy security and dependence on imported fuels, as well as the deteriorating status of environment by global warming causes that there are more and more new technologies using renewable energy sources nowadays.

In the medium- and long-term perspective a significant changes are needed regarding means of transport in ensuring "sustainable mobility", while in the horizon of short-term solution is i.a. the implementation of natural gas as a transport fuel. Natural gas can be used in two forms: as a gas (CNG – Compressed Natural Gas), and as a liquid (LNG - Liquefied Natural Gas). Currently the most often used is CNG fuel [1]. The vehicles, which can be supplied by CNG or LNG fuels, are called Natural Gas Vehicles (NGV).

2. Properties of LNG fuel

Physical state of natural gas is significant only in the storage of this fuel, the refueling process, as well as the type and size of fuel tanks. LNG is a liquefied mixture of hydrocarbon gases with small admixtures of nitrogen. In each liquefaction station, main component of LNG is methane (over 95%) [2]. The properties of LNG, CNG and diesel fuel are presented and compared in Tab. 1.

Tab. 1. Comparison of properties of LNG, CNG and diesel fuel

	LNG	CNG	DIESEL FUEL
Density	450.36 kg/m^3	0.654 kg/Nm^3	833 kg/m^3
Calorific value	35.4 MJ/dm^3	21.0 MJ/dm^3	43.15 MJ/dm^3

The density of LNG is more than 3 times higher than CNG. This means that use of LNG as a fuel can reduce volume of tanks and allows for use of smaller, lighter containers [3]. The LNG bus by Solbus is shown on the Fig. 1, and CNG bus by Irisbus Citelis with fuel tanks located on the roof is shown on Fig. 2.

Fig. 1. Solcity LNG bus by Solbus (private photo)

Fig. 2. CNG bus by Irisbus Citelis in depot in Wałbrzych (private photo)

LNG powered buses don't have the fuel tanks on the roof in general, because due to a smaller capacity of the tank there was the ability to install it in the space above the engine compartment at the height of the rear window. The LNG tank is shown in Fig. 3.

Fig. 3. LNG Container (private photo)

In the Tab. 2 there were compared the fuel tanks capacities of different types of buses, fuelled by diesel oil, CNG and LNG.

Tab. 2. Comparison of fuel tanks capacities in different bus models

Brand and model of bus	Length [m]	Fuel type	Fuel tank capacity [dm^3]	Fuel mass in tank fuel [kg]
Solaris Urbino	12	CNG	1 284 *)	168
Solaris Urbino	12	Diesel fuel	250-350	208-292
Solbus Solcity	12	Diesel fuel	250	208
Solbus Solcity	12	LNG	333	150
Solbus Solcity	12	CNG	1 260 *)	165
Man Lion's Classic G	12	Diesel fuel	300	250
Man Lion's City G	12	CNG	1 220 *)	160
Autosan Sancity 12LF	12	Diesel fuel	285	237

*) *Water capacity of the container*

3. Measurement methods

For measuring, the consumption of LNG or CNG by engines in the Environmental Protection Centre there is a mass flowmeter by Emerson Company CMF025M type with Micro Motion sensors. The sensing element in the flow meter uses the Coriolis effect [4].

A mass flowmeter is comprised of two main components, a sensor (primary element) and a transmitter (secondary). A mass flowmeter infer the gas mass flow rate by sensing the Coriolis force on a vibrating tube or tubes. The conduit consists of one or more tubes which are vibrated at their resonant frequency. Sensing coils located on the inlet and outlet sections of the tube(s) oscillate in proportion to the sinusoidal vibration. During flow the vibrating tube(s) and gas mass flow couple together due to the Coriolis force causing a phase shift in the signals produced by the sensing coils. The phase shift, which is measured by the mass flowmeter transmitter, is directly proportional to the mass flow rate.

A Micro Motion Coriolis curved tube sensor includes (Fig. 4): Flow Tubes, Drive Coil and Magnet, Pickoff Coil and Magnet, RTD, Process Connection, Flow Splittem, Core Processor, Case.

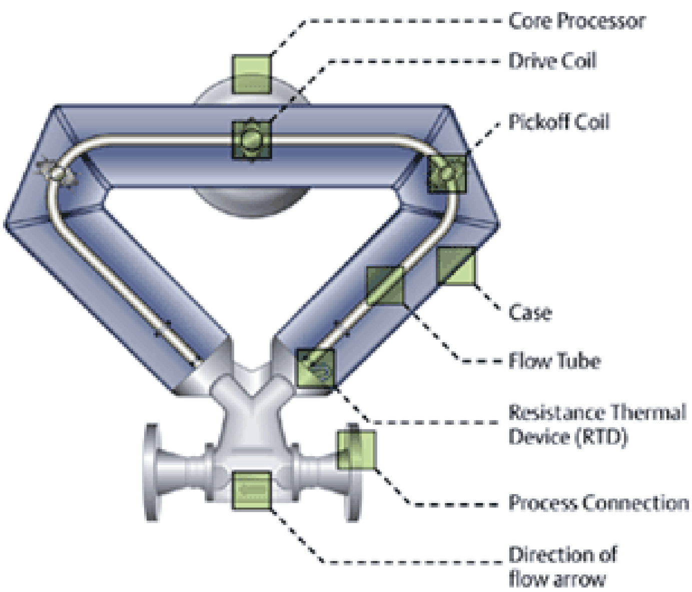

Fig. 4. Micro Motion Coriolis curved tube sensor – Overview [5]

In Micro Motion flowmeters that have dual parallel flow tubes, process fluid entering the sensor is split with half of the fluid passing through each flow tube. During operation, a drive coil is energized causing the tubes to oscillate in opposition to one another.

Micro Motion magnet and coil assemblies (called pick-offs) are mounted on the opposing flow tubes. Pickoff coils are mounted on the side legs of one flow tube, and magnets are mounted on the side legs of the opposing flow tube.

Each coil moves through the uniform magnetic field of the adjacent magnet. The voltage generated from each pickoff coil creates a sine wave. Because the magnets are mounted on one tube, and the coils on the opposing tube, the sine waves generated represent the motion of one tube relative to the other.

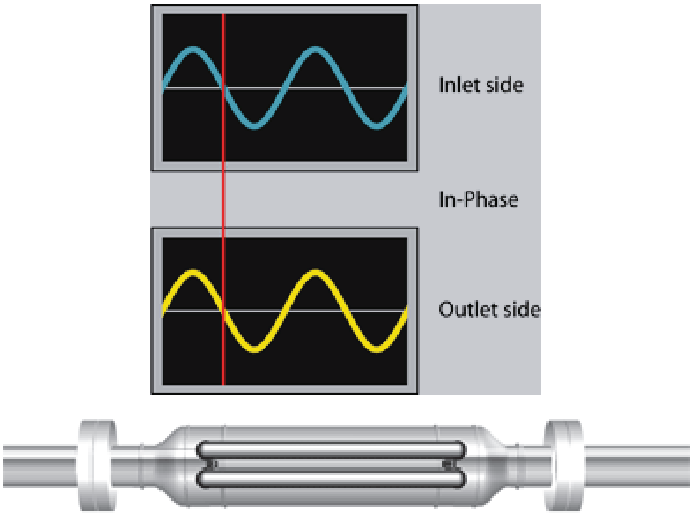

Fig. 5. Flow Operating Principle: Curved Tube—No Flow—Tube Motion [5]

The flow tubes oscillate in opposition to one another, similar to a tuning fork.

Both pickoffs (the one on the inlet side and the one on the outlet side) generate sine wave signals continuously when the tubes are oscillating. When there is no flow, the sine waves coincide.

During a no flow condition, there is no Coriolis effect. Thus the inlet motion and outlet motion is in phases and the sine waves coincide with each other.

The mass flow moving through the inlet legs of the flow tubes generate a Coriolis force that resists the vibration of the flow tubes. As the mass flow moves through the outlet legs, the Coriolis force adds to the vibration of the flow tubes. It is the opposite direction of the Coriolis force between the inlet and outlet legs that result in the twisting motion that is used to measure mass flow rate.

As a result of the twist in the flow tubes, the sine waves generated by the pickoffs are now out of phase with each other because the inlet legs are lagging behind the outlet legs.

The time delay between the two sine waves is measured in microseconds, and is called Delta-T. Delta-T is always directly proportional to the mass flow rate – the greater the Delta-T created by the Coriolis force, the greater the mass flow rate.

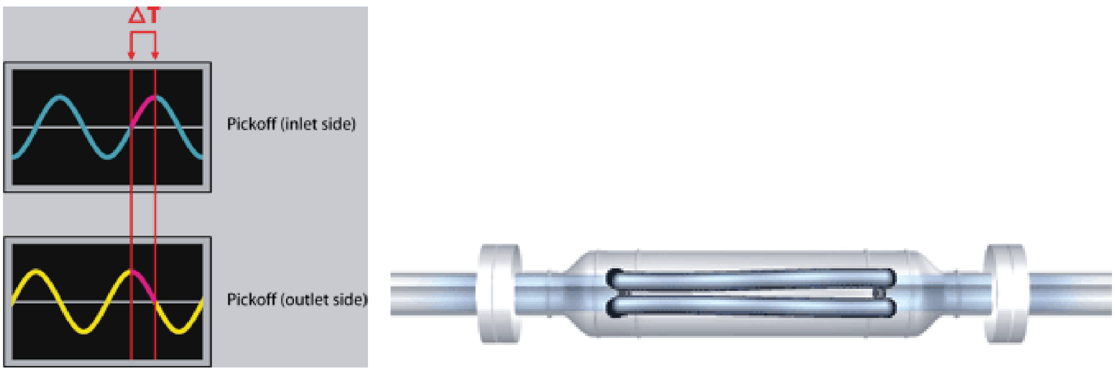

Fig. 6. Flow Operating Principle: Curved Tube—Flow—Coriolis Effect [5]

The relationship between mass, stiffness, and natural frequency is the basis for density measurement in a Coriolis flowmeter. To understand this relationship, consider the spring and mass system.

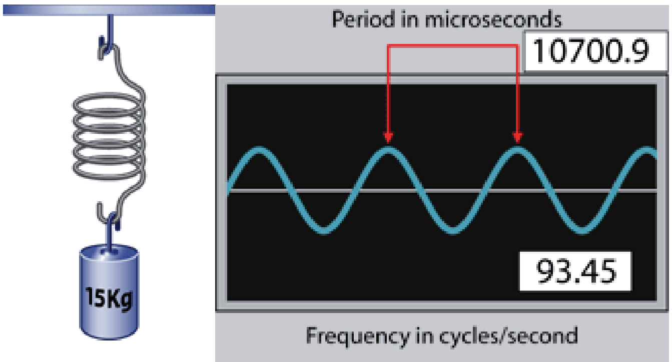

Fig. 7. Density operating principle in a Coriolis flowmeter

In the Coriolis sensor, the tubes correspond to the spring (Fig. 7). The mass of the tubes plus the mass of the fluid they contain, correspond to the mass at the end of the spring. The stiffness of the flow tubes remain essentially constant. Therefore, the mass (density) of the fluid contained in the fixed volume of the flow tubes is the only variable effecting the natural frequency.

During operation, a drive coil causes the tubes to oscillate at their natural frequency.

Frequency is measured in cycles per second. Tube period is the reciprocal of natural frequency. Micro Motion Coriolis flowmeters measure density by measuring tube period in microseconds per cycle.

Fluid density is directly related to the measured tube period.

4. Tests results discussion

The objects of the tests are two 12-meter buses. During the test first vehicle (bus no. 1) was powered by natural gas (NG) contained in the tanks in liquid form (LNG) and the second vehicle (bus no. 2) was powered by diesel fuel. Other details of both vehicles are given in Tab. 3.

Tab. 3. Characteristics of tested buses

Parameter	Unit	Bus no. 1	Bus no. 2
Dimensions (length x width x height)	[m]	12 x 2.55 x 3.1	12 x 2.55 x 3.05
Empty weight	[kg]	11 150	11 769
Fuel		LNG	Diesel oil
Maximum power	[kW]	239	206
Engine capacity	[cm^3]	8 880	9 290
Fuel tank capacity	[dm^3]	150	300

Several measurements were performed in each passing direction of measuring distance (there and back) for both tested objects. From all the directions, consumption has been appointed in accordance with the methodology set out in Chapter VI, Section C of SORT standard. The values given below are the relative average values of the fuel consumption measured in direction 1 and the direction 2 (Tab. 4).

Tab. 4. Relative fuel consumption of tested vehicles [%]

Bus no. 1	Bus no. 2
99.9	100

*) *In percent of fuel consumption of bus No. 2*

5. Conclusions

The article discusses the tests results of the fuel consumption in two city buses with similar design parameters (see Tab. 3), fuelled with liquid natural gas or diesel. The buses were characterized by an identical fuel consumption measured in the same conditions (SORT test 2). The difference in fuel consumption was 0.1%, which is less than the uncertainty of the measurement result.

In the bus powered by methane, the fuel was stored in liquid form (LNG). The LNG tank can store nearly 3.5 times more fuel (by mass) than in the tank for compressed natural gas (CNG). For example, a 12-meter bus by Solbus, equipped with an engine powered by methane tanks, manufacturer offers both CNG and LNG tanks. The LNG tank can hold 150 kg of fuel, and CNG tank – 165 kg. Taking into account the capacity of these tanks, it is possible to obtain respectively 0.45 kg from 1 dm^3 of fuel tank capacity for LNG tank, and 0.13 kg fuel from 1 dm^3 of fuel tank capacity for CNG tank. This allows the use of smaller LNG tanks in buses while maintaining the same coverage.

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