Automation of measurement and control for the process of fluid consumption in precision measurement equipment

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Abstract. Methods for measurement of volumetric flow are estimated. Contains the detailed description of Methods for direct flow measurement with the use of a measuring cylinder equipped with a free split piston are described in details. Original diagrams describing connections between sensors and operation units which input and output signals are processed with special algorithms are demonstrated. The example describing the effect of parameters of the measurement tool basic hardware units on the accuracy of measurement is considered.
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Introduction

There are very actual tasks connected with the operation of powerful vehicles, such as trains, big trucks, vessels and spacecrafts and improvement of flow rate accuracy control. Considering the worldwide volume of fuel consumption and fuel prices even a small improvement in accuracy of fuel flow control is equal to saving of hundreds of million dollars. The improvement of metering accuracy methods applied for different liquid components during the manufacture of strategic materials, medicine and other products is also important. This is because such accuracy is connected with the quality of the final product.

Contemporary measurement devices are equipped with microcomputers making a measurement process better by using the digital compensation of basic and complementary errors applied to the end result [1]. But application of information technologies does not give the expected result in case of the weak function of the measured parameter correlation and destabilizing factors.

Methods for measurement of volumetric flow of fluids can conditionally be divided into direct and indirect or velocity methods. The method of a measuring tank and method of a measuring cylinder can be considered as direct.

Indirect method, or generally a method of velocity flow measurement is applied in connection with improvement of electric methods of measurement. The basic field of application is connected with the implementation of continuous automated flow metering of liquid and gaseous mediums. Orifice plate method, electromagnetic method, rotameter, calorimetric, ultrasonic, tachometric and Coriolis methods can be considered as velocity volumetric flow measurement methods.

The common feature for all described methods is metering of flow passing through a tube with the known cross-section at a certain speed ϑ [nu]. The value of the speed ϑ [nu] is determined using parameters of a liquid medium which has a hard correlation with the flow velocity.

The volumetric flow rate is calculated using a following formula:

$$V=S\cdot\vartheta\cdot\dot{t},$$

where V - fluid volume, S- cross-section of the tube, ϑ [nu] – flow speed, $\dot{t}$ [tau] - metering time. Values of S and $\dot{t}$ [tau] can be specified and determined with a high accuracy. The value of flow speed ϑ [nu], on the contrary, can be determined using indirect methods mentioned above.

The detailed classification of the most widespread volumetric flow measurement methods or is illustrated on Figure 1.

Method of measuring tanks has been known for several thousand of years. This method consists of a measurement using a bucket of the known volume. For example, this could be a completely filled amphora or a bucket.

Much later were invented graduated glass made vessels along with a development of glass vessels manufacture. Using such vessels different fluids could be measured by using the meniscus level. Because of the high measurement accuracy this method is applied in metrology and modern manual production of different solutions and medicines where graduated glasses and cylindrical graduated measuring containers are applied.

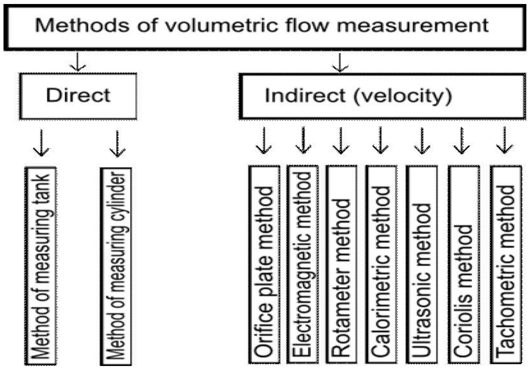

Figure 1. Classification of volumetric flow measurement methods

The method of measuring containers was the only method for measuring the volume of fluids before electrical means of measurement were invented. For example, Archimed used this method during the experimental confirmation of buoyancy force acting on bodies immersed into the fluid in 250-212 b.c. This method is still applied while creating test facilities for volumetric fluid flow because it provides the high measurement accuracy.

The volumetric flow measurement method cannot be widespread in control systems due to the absence of equipment providing the direct automated flow metering.

Requirements for improvement in automation of control process stipulated alternative indirect measurement methods.

Orifice plate method

The first method is orifice plate method of measurement. This method is applied for fluid, gas and steam flow measurement. The flow velocity is determined using the value of pressure drop in a tube with a reduced cross-section area.

This measurement method is based on the relation of pressure drop inside the tube with a restrictive flow orifice plate installed inside the tube and the flow rate of the measured medium [3].

The volumetric flow rate G_0 is determined using a well-known formula:

$$G\_0 = cEf[2/\rho(P\_1 - P\_2)]^{0.5}$$,

where E – input coefficient, C – discharge coefficient**.** Both these coefficients depend on the ratio between the minimal area of the orifice plate (f) and flow velocity at a volume density value ρ [rho]. The pressure drop

($P_1 - P_2$) inside the tube with a reduced cross-section area is measured with a differential pressure gauge indicating flow units.

In case of remote data transmission the differential pressure manometer is equipped with a transformer connected with a secondary device and other equipment.

This flow measurement method is the most widely used, orifice plates and differential pressure gauges are manufactured by all well-known equipment manufacturers in the world [4]. This method is basically used for measurement of steam, gas and fluid flows inside the pipe with a diameter more than 300 mm. The considered principle of measurement is based on the flow passing through the orifice plate and its velocity increases in comparison with the velocity before the orifice. The velocity increase along with a kinetic energy causes the decrease of a potential energy and static pressure. The flow value may be measured using a known gauge line by determining the pressure drop value at the orifice measured with the differential pressure gauge. The calculation of volumetric flow according to reading of the differential pressure gauge is carried out using microprocessing equipment.

Implementation of this measurement method requires specific conditions.

1. flow pattern before and after the orifice plate should be turbulent and steady;

2. the flow should completely fill the entire pipe cross section;

3. flow phase should not change while passing through the orifice plate;

4. the internal tube body should contain no deposits and other kind of pollutants that change its cross section before and after the orifice plate along with the orifice itself.

Electromagnetic method

Electromagnetic method of flow measurement is based on Faraday's law of electromagnetic induction [5, 6]. According to this law the voltage is induced when a conducting fluid moves through the magnetic field. The voltage produced is directly proportional to the flow rate. This method is based on measuring the voltage induced with the flow of of a conducting fluid and directly proportional to the flow rate inside the pipe or its consumption [7].

Electromagnetic flow meters are applied for measuring flows of conducting aggressive, viscous, abrasive mediums, pulps and liquid metals. Manufactured electromagnetic flow meters are designed for measuring flows of fluids with electric conduction value not less than 10^{-3} Cm/m .This value is equal to the electric conduction value of water. There are special flow meters which can measure flows of fluids with electric conduction value up to 10^{-5} Cm/m. At present time electromagnetic flow meters are widespread devices assigned for water flow measuring in water pipes with a diameter less than 250 mm. Minimal value of electric conduction of a measured medium should be considered as a disadvantage of electromagnetic flow meters because this narrows a field of their application. Another disadvantage is a low level of information signal measured in microvolts**.** This fact stipulates for a higher protection of a transducer and connection lines from external interferences.

Method of variable area measurement or rotameter method

Flow meters with a constant differential pressure are also called variable area meters. This group of flow meters consists of rotamers, piston and float flow meters. This method is based on the measurement of a vertical float rotation depending on the medium flow pushing the float upwards in a conic camera [8]. Each value of the flow corresponds with a certain flow position: the heavier flow is the higher is a float position. In this case the float weight acts as a counterforce. The pressure drop value inside the rotameter is constant that is why rotameters are called constant pressure drop flow meters.

The area of an annular ring between surfaces of a float and conic camera changes depending on the value of a measured flow. Pressure drop before and after the annular ring remains constant. The force of gravity applied to a float or piston is a counterforce. Rotameters are widely applied in laboratories and different industries. They are assigned for measurement of smoothly changing volumetric homogeneous flows of pure fluid and gas or fluid containing a small amount of pollutants and gas with possible disperse foreign particles. They are also applied as indicators for medium flow in gas analysis instruments and other devices.

Rotameter consists of a conic glass (for a transparent medium) or metallic tube with a widening top and a metering float inside the tube. The float surface contains twist rifling for rotation around its axis by means of a relative movement of a flow. Due to the presence of twist rifling the float has no contact with a tube wall and this eliminates the action of friction forces on the float position. The float is pushed up vertically by a fluid or gas flow, simultaneously rotates around its axis and centers in the middle of the flow. The float rotation along a glass tube graduation allows to evaluate a volumetric flow rate within a time unit (liter per hour, cubic meter per hour). There are rotameters with a float making no rotation movements around its axis. It is also possible to install an electric connection port in case the device is equipped with a sensor indicating a float position inside a conic camera. However, the microprocessor based processing of electric signals received from float sensors does not provide the improvement in measurement accuracy because it is restricted with conductivity, density and viscosity parameters of a measured fluid.

Calorimetric method

Measurement of fluid and gas flow with a calorimetric method is based on a heat loss of a hot body caused by a fluid or gas flow. Temperature sensor heated with direct current is used as a hot body [9]. Calorimetric method implements the principle of a heat loss measurement. A fluid or gas flow transfer heat from a hot body to another temperature sensor.

Calorimetric flow velocity sensors are often called thermal anemometers and better applied for measurement of low flow values of liquid or gas (approximately 30-3000 cm per second for gas) where application of differential pressure sensors is irrational. The basic advantage of calorimetric flow meters is a compact size (dimensions) which enables to make measurements in tubes with very small diameters. Another advantage is the absence of moving mechanical parts and a wide dynamic range.

The basic disadvantage is a fact that flow meter reading is affected by acute temperature and property changes of a measured medium. For example, there may be density or thermal conductivity properties of a medium. Information technologies are applied for controlling output signals. However, further improvement of thermal anemometers accuracy is restricted by existing faults depending on density and thermal conductivity characteristics of the measured medium.

Ultrasonic method

Ultrasonic method of volumetric flow measurement is based on a propagation of ultrasonic waves in the fluid [10]. The average fluid velocity can be calculated as a result of ultrasonic measurements. This velocity is determined by measuring a propagation velocity and a phase of ultrasonic waves. The principle of ultrasonic flow meter operation is based on measuring of an acoustic effect which arises when ultrasonic waves propagate through the measured fluid or gas flow [11].

Two groups of flow meters are currently used. The first group is based on the ultrasonic waves propagating through a measured medium (transit time flow meter). The second group is a Doppler flow meter.

The first group of flow meters is the most widespread. Ultrasonic waves are produced in such flow meters by means of piezoelectric elements and propagate in and against and the direction of flow. Time difference values of ultrasonic pulses propagating between receiving and transmitting transducers in and against the direction of flow, i.e. velocity of ultrasonic propagation depends on the flow velocity.

Basic disadvantages in application of the ultrasonic method is connected with the fact that velocity of ultrasonic waves depends on physical and chemical properties of a medium, such as temperature and pressure. And this dependence has a bigger effect compared to a medium velocity. As a result, the real ultrasonic propagation velocity in a flowing medium has a small difference compared to that in a stationary medium.

Ultrasonic measurements are carried out with application of two piezoelectric transducers installed on opposite sides of a tube (along the tube axis) in a distance of at least 100 mm. Transducers can operate in radiation and reflection modes. Without an application of special technical and software solutions processing of output sensors signals from is rather difficult.

Coriolis method

Coriolis force affects mass moving along the radius of a rotating system. Direction of this force is perpendicular to the rotation axis and flow direction. Value of this force is proportional to the rotation velocity and radical velocity of the mass. Coriolis flow meters have good measurement results for fluids with a constant chemical composition and do not need the pressure and temperature compensation. Oscillations with a frequency resonant to a tube's frequency or a frequency of its harmonic are excited inside an O-shaped area of a tube. Sensors at the inlet and outlet ends of a tube are installed symmetrically to the electric magnet in order to register phases of tube oscillations. Sideway acceleration acts on a fluid flowing inside the tube. Oscillations at the inlet fade because of the terminal value of Q-factor. While a fluid is flowing inside the tube it transfers its energy to the tube and oscillations increase at its outlet end. Signal phases measured at the inlet and outlet ends of the tube will be different and this difference is directly proportional to the mass flow. Coriolis flow meters have a very small effect on pressure losses inside a tube. The same device can be applied for measuring of density and flow values. Frequency of a filled tube area is inversely proportional to the fluid density. This frequency value is determined for measuring of fluid density. Coriolis flow meters have a small measurement error (about 0,5% from the measured value) in case of fluids with a constant chemical composition. However, these flow meters are sensitive to vibrations and have installation restrictions relatively to the center of gravity. Coriolis flow meters have no mechanical components and their output signals are processed with application of electronic circuits [12]. Microprocessors are applied for processing output signals of Coriolis flow meters. However, these devices do not insure against errors caused by changes in a flow chemical composition, vibrations, density and viscosity of a fluid.

Tachometric method

Tachometric method of measurement is based on control of a specified shape body moving in the fluid. As a rule tachometric flow meters have a special element rotating with a velocity proportional to the volumetric flow. Tachometric flow meters types are: turbine, vane, ball-type, rotor and chamber. Sometimes vanes are called turbines but they have a difference in construction of blades and flow supply method. These devices provide a high accuracy in measurement at constant viscosity and density characteristics of a fluid. The measurement error for such flow meters is just ? 0,5 % in case a measured fluid has no pollutants and mechanical impurities [13].

All considered and omitted tachometric methods of volumetric flow measurement, including exotic, have a complicated and multivariate correlations between an actual volume and indirectly determined flow velocity. As a rule, any analytic correlations of a measured parameter and actual volume of a fluid are true in a narrow range of influencing quantities. Any physical, chemical, electrical or composition characteristic changes in controlled fluid along with parameters of the primary transducers, as a rule result into increase in measurement error. Application of indirect methods for decrease of measurement errors needs measurement systems with multivariate sensors of influencing quantities and volumetric flow control according to ideal analytical relations.

A search for performance increase and volumetric flow control with a modification of a direct automated metering are actual tasks. Even a small improvement in measurement accuracy may result in a great improvement in quality and lead to multi-million economy in different industries and consumption of fuel and process liquids. There are several ways approaching to a solution to these tasks [14, 15].

Method of direct volumetric flow measurement with application of a measuring tank and measuring hydraulic cylinder with a floating piston.

Method of direct volumetric fuel flow measurement with application of a measuring tank [15] and measuring hydraulic cylinder with a floating piston [16-18] becomes a more prospective method of volumetric flow measurement because it improves the accuracy. This method allows to designing precision measurement instrument with different ranges. But measurement accuracy in such devices depends on geometric properties of a measuring mechanism along with sensors errors and algorithms of control and processing of information. Current technologies enable precise implementation and maintenance of geometric characteristics of a measuring mechanism during the operation process. Methods of calculation and selection of geometric properties of a hydraulic cylinder are essential along with the detailed study of hardware and software effect on measurement accuracy. These methods are necessary for evaluation of obtainable accuracy boundary of precision measurement instrument .

Figures 2 and 3 illustrate a basic example of a volumetric flow measurement system structure of a powerful tractor, locomotive and marine engines consuming diesel gas oil with two stable conditions [16].

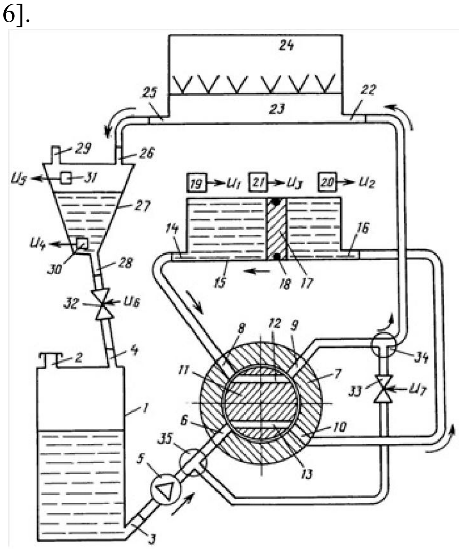

Figure 2. Volumetric flow measurement system of a diesel engine (stable condition 1).

Figures 2 and 3 contain: 1- fuel tank; 2,3,4 – fuel tank tubes; 5 – fuel pump; 6,8,9,10 – stator tubes of a flow control device; 7 – housing of a flow control device; 11- rotor of a flow control device; 12,13 – rotor tubes; 14, 16 - adapters of a measuring hydraulic cylinder; 15 – measuring hydraulic cylinder; 17 – floating piston of the measuring hydraulic cylinder; 18 – piston O-ring; 19, 20 – end piston position alarms; 21 – extended frequency indicator of a piston position; 22,25 – engine inlet manifold tubes; 23 – engine inlet manifold; 24 – internal combustion engine; 26, 28, 29 – measuring tank tubes; 27 – measuring tank; 30 – low fuel level alarm of the measuring tank; 31 - top fuel level alarm of the measuring tank; 32,33 – electromagnetic valves, 34,35 – connectors.

Figure 2 illustrates the first stable condition. In this position of the rotor (11) the floating piston (12) under pressure of the fuel pump is moving to the left side and pushing the fuel out of the left side of the hydraulic cylinder (15) through elements (14), (8), (12), (9), (34) and (22) into the engine inlet manifold (23). When the floating piston (17) has reached its end left position it activates the alarm (19) and the signal U_1 makes the rotor (11) rotate by 90º and the system reaches the second stable condition (Figure 2). At this stable condition the piston (17) under pressure of the fuel pump (5) is moving to the right side and pushing the fluid out of the right side of the hydraulic cylinder (15) through elements (16), (10), (13), (9), (34) and (22) into the engine inlet manifold (23). This stable condition remains until the end piston positions alarm (20) is activated and its signal U_2 the rotates the rotor(11) by 90º and the system returns to its first stable condition.

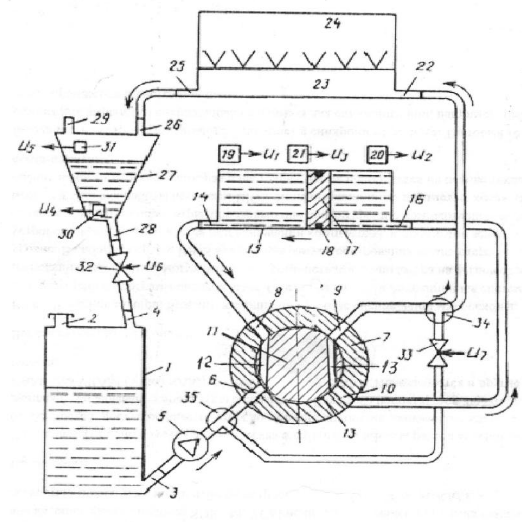

Figure 3. Volumetric flow measurement system of a diesel engine (stable condition 2).

Figure 4 illustrates the algorithm of rotor (11) position control.

Details of this algorithm implementation may affect on the accuracy of measurement because of the end time interval for the rotor (11) transition from one stable condition into another. The real time value of a flow control device transition from one stable condition into another is lying between 10^{-2} and 10^{-1} seconds. Specific features of the flow channel structure The indirect effect on control adequacy consists of breach of monotonous fuel supply into the inlet manifold (23). In other words, these transitions do not affect on the accuracy of measurement owing to non-combustible properties of the fuel. But they affect on the operation mode of the engine and the fuel consumption mode.

Figure 4 contains: A - process beginning (power on); B – initial conditions settings (operation start with zero or specified non-zero value); C – operation mode setting (metering within a certain period of time, certain number of cycles, fluid volume, metering before the fluid passage is complete and other); D – determination of a piston direction and travel velocity (17) inside the hydraulic cylinder (15);

E,F – control for operation of alarms (19) and (20); G – alarm operation waiting; H,L – signal generation of rotor (11) rotation by 90º (presence of two signal generators H and L is necessary at reverse motion of the rotor (11); M – control for emergency situations (for example, difference between a piston phase (11) and signals at generators outlets H and L; Z – visualization of a flow control system condition.

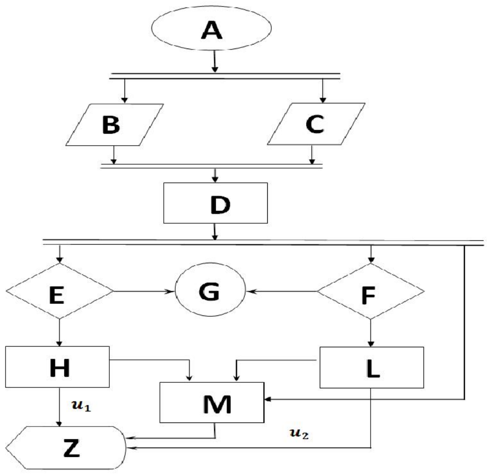

Figure 4. Algorithm of rotor position control

During operation all controlled volume of the fuel is continuously pumped through the measuring hydraulic cylinder (15). Figure 5 illustrates the diagram of the algorithm of volumetric flow storage control.

Figure 5 contains: A- process beginning (power on); B – initial conditions settings (operation start with zero or specified non-zero values); C – control mode setting (metering within a certain period of time, certain number of cycles, fluid volume, metering before the fluid passage is complete and other); D – fluid flow storage control within a specified time interval; E – flow rate determination process; F – collection of information about a storage flow for a further presentation on a display H; G – collection of information about the flow rate for further presentation on a display H; H- display for a visual presentation of information about the flow rate and storage flow.

The basic implementation of the algorithm of volumetric flow storage control is calculation of stable conditions of the measuring hydraulic cylinder and determination of the phase of the piston (17) intermediate condition at the beginning and the end of control period. This implementation is carried out with application of extended frequency indicator (21). With implementation of this algorithm it is also possible to implement the algorithm of flow rate determination in ON-LINE mode. The diagram of the algorithm of flow rate determination is illustrated on Figure 6.

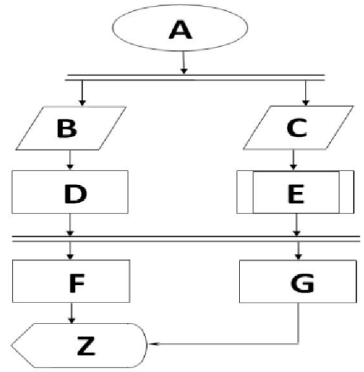

Figure 5. Diagram of the algorithm of volumetric flow storage control

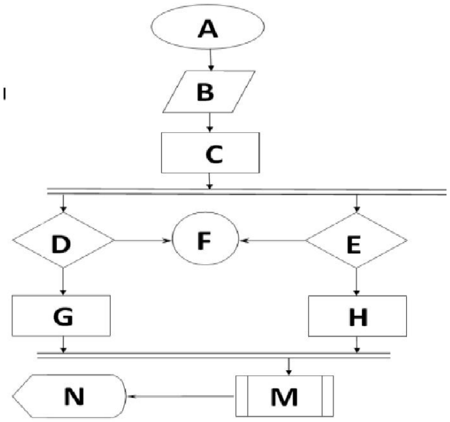

Figure 6. Example of the algorithm for a flow rate determination

Figure 6 contains: A- process beginning (power on); B – initial conditions settings (interval of a piston travel (hysteresis of output signals of extended piston position sensor (21)), metering frequency and so on); C – control for extended sensor (21) output signal values; D,E – comparison of sensor (21) output signals with set values; F – comparison result waiting; G,H - beginning and end of a metering interval; M – flow rate metering process; N – visualization of control results.

Flow rate is determined by travel of a piston inside the hydraulic cylinder within a certain period of time. It is also determined by a period of time within which a piston travels from one certain position to another. These positions are determined by a change of the output frequency of the sensor (21).

The specific feature of diesel engines is an incomplete consumption of fuel received from the inlet manifold (23). As a result, a certain amount of fuel is drained into the measuring tank (27) through tubes (25) and (26). Measuring tank (27) is equipped with low (30) and high (31) fuel level alarms. Full filling of the measuring tank activates the alarm (31). Alarm (31) signal U_5 generates signal U_6 for electromagnetic valve (32) opening and fuel from the measuring tank (27) is drained into the fuel tank until the alarm (30) is activated. As a result, volume of fuel drained from the measuring container (27) into the fuel tank (1) should be deducted from the results of volumetric flow storage control. Metering of fuel returned to the fuel tank (1) and control for operation of the electromagnetic valve (32) are subject to implementation using the algorithm of corrective control of a volumetric flow. Diagram of this algorithm is shown on Figure 7.

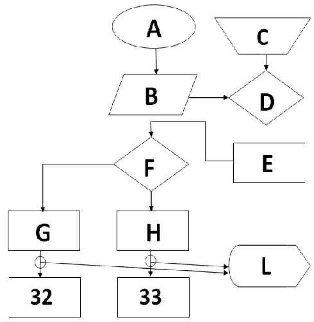

Figure 7. Algorithm of corrective control of a volumetric fuel flow

Figure 7 contains: A - process beginning (corrective control mode on); B - initial conditions settings (value of effective fluid volume containing in the measuring tank (27) with a level value changing from alarm (30) to alarm (31)); C – corrective control mode on and off; D – decision on activation or blocking of corrective control mode; E – control for activation of top fuel level (30) and low fuel level (31) alarms inside the measuring tank (27); F – decision on activation of valves (32) or (33); G,H – generation of electromagnetic valves (32) and (33) control signals; L – visual presentation of corrective control results.

During the detailed implementation of this algorithm there is uncontrolled drain of fuel from the manifold (23) into the measuring tank (27) at the time of U_6 signal action. That is why special important implementations of the measuring instrument can be equipped with an additional stopper electromagnetic valve installed between tubes (25) and (26). Closing this valve using signal U_6 eliminates uncontrolled drain from the manifold (23) into the tank (27) during fuel drain from the tank (27).

Interaction of measuring instrument operation algorithms and storage, formatting and presentation of information in digital and graphic formats are subject to implementation of the algorithm of operation control. Diagram of this algorithm is illustrated on Figure 8.

Figure 8 contains: A - process beginning (measuring instrument power on); B – control for rotor (11) (see the diagram on Figure 4); C – process of volumetric flow storage control (see the diagram on Figure 5); D – flow rate determination process in ON-LINE mode (see the diagram on Figure 6); E – process of corrective control of a volumetric flow (see the diagram on Figure 7). Operation control is important for measuring instruments of powerful diesel engines.

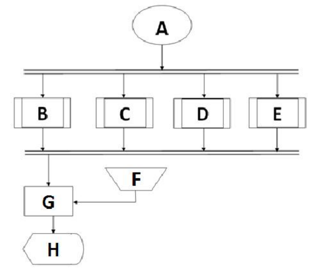

Figure 8 – Algorithm of operation control

Software component of the measuring instrument contains processes described with diagrams of algorithms mentioned above. The process of measuring instrument control is concentrated in selection of a necessary combination of these algorithms. As a result, the measuring instrument has a high functionality and flexibility and can easily be adapted for different modes of operation.

Structure diagram of a hardware component of the volumetric fuel consumption measuring system applied for internal combustion engines is illustrated on Figure 9.

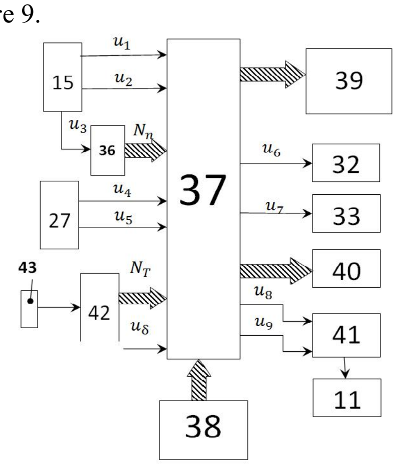

Figure 9. Structure of a hardware component of the volumetric fuel consumption measuring system

This system includes a converter (36) of signals received from a sensor (21) and converting signals into code Nп of a piston (17) position inside the cylinder (15) or into the value of fuel volume inside one of cylinder (15) chambers, processor (37) with a control panel (38), display (39) and output connector (40) for connection of a user. Besides that, control output connectors of the processor (37) are connected to the electromagnetic valves (32) and (33), electric drive (41) of the flow control device (7). Measuring instrument may also have a digital thermometer (42) with output connectors of digital code Nт, temperature sensor (43) and signal input from a built-in or additional fuel level or volume sensor installed inside a fuel tank.

Processor (37) carries out digital processing of signals U1, U2, U4, U5, U6 codes Nк and Nт and generates controlling signals U6...U9, presents results of information processing and indications of basic blocks on a display (39) and output connector (40). With the use of a control panel (38) operator can change the data format of indicated information and, if necessary, switch operation modes of processor (37).

All considered algorithms of the measuring instrument do not contain any essential sources of errors at direct flow measurement method providing that flow laminarity retains in components of a measuring instrument structure. Contemporary construction materials and processing technologies eliminate errors caused by modification of geometric characteristics of a measuring hydraulic cylinder (15) and floating piston (17) owing to an insignificant extent of such modifications. Integration of a sensor and digital fuel thermometer into a hardware structure enables implementation of control for a temperature effect on the mode of fuel consumption and, if necessary , carry out the temperature offset using software components.

The example below demonstrates calculation of basic parameters of a volumetric flow measuring instrument. This example contains relations providing laminarity of a fuel flow in measuring instrument components.

1. Choose effective volume V_e of the measuring hydraulic cylinder (15) according to the condition: $V_e \cdot t_{emin} \times dV/dt$, where dV/dt – peak fuel consumption rate of a locomotive diesel engine, liters per minute, temin– minimum time necessary for a piston (17) to travel from one end position to another. At dV/dt=2 l/min and te min=0.5 min, getting V_e=1000 cub. cm.

2. It is reasonable to range the measuring tank (27) volume within:

$V_o=(1\text{-}2)V_e$. Choose $V_o=V_e$=1000 cub. cm.

3. Following practical purposes choose the full piston travel L_e within (30?5) cm. Suppose L_e=30 cm.

4. As $V_e=L_e \cdot S_e$, where S_e=Ve/Le=1000/30=33.33 sq.cm - square of the piston (17) end surface. In the meanwhile $S_e=\pi\ D_e$. Here D_e=12.73 cm.

5. Define the pressure drop $P_т$ inside the hydraulic cylinder (15) according to the condition: Pт = Fп/Sп, where Sп– square of the piston (17) end surface, measured in sq. cm, Fп– force sufficient to overcome friction forces between the piston (17) and housing of the hydraulic cylinder (15), measured in kg. Real value of $F_п$=0.5 kg and $S_п$=33.33 sq. cm result in $P_т$=0.015 ATMG. It is obvious that the pressure drop $P_т$ on the piston (17) is not significant and has almost no effect on operation of the fuel supply system inside the engine.

6. Determine control error value of the volumetric fuel flow owing to the variation of threshold values of piston end position alarms (19) and (20). Actual value of the alarm operation error δ_φ at the amount of 0.5 mm and piston (17) travel at the amount $L_ц$=300 mm result in δ_φ in %: $\delta_\varphi = (1/L_ц)\cdot 100\%=0.165\%$.

7. Including the error value of a reference gage δ_o=0,1% the total relative error of the direct volume metering with the use of a measuring cylinder and at the normal law of errors would not exceed 0.2%.

8. By choosing a construction of the measuring container (27) and applying digital processing of information the relative error δ_β of control for residual fuel draining from the manifold (23) into the container (27) would not exceed 0.1%.

9. Total relative error δ_γ of the measuring instrument at the normal law of errors may be determined using the formula: $\delta_\gamma = [\ \delta_\varphi^2 + \delta_o^2 + \delta_\beta^2\ ]^{1/2}$ In this case we have $\delta_\gamma \leq 0.25\%$.

10. Determine the number of cycles N and the piston (17) travel length L for 1000 liters of fuel.

$N=1000/2V_o=500$, $L = 2\cdot N\cdot L_ц$= 2 x 500 x 0.3 = 30 meters

Wear resistance characteristics, accuracy and reliable operation of the measuring instrument depends on the quality of materials and configuration. The most important elements of the measuring instrument are flow control device (7) and measuring hydraulic cylinder (15). It is reasonable to make the housing (61) of the hydraulic cylinder of a wear resistant dielectric material such as glass or teflon. Besides the improvement of its lifetime this also decreases a piston (17) travel force. And this also creates the possibility to implement the sensor (21) on a basis of a high frequency delay system. Implementation of a floating piston displacement transducer of the measuring hydraulic cylinder with a storage sensor is already well-studied [19].

Lifetime period of electromagnetic flow control device (7) and electromagnetic valves (32) and (33) which guaranteed by a manufacturer is about 500 thousand operations. The most repeated process is a flow control device (7) switch. The volume of fuel flowing through the measuring cylinder (15) after 500 thousand operations can be determined using the formula: $V_т=500000 \cdot V_o$=500000 liters. With the tank volume of $V_б$=6000 liters and average weekly fuel consumption the lifetime value of a flow control device (7) will be sufficient for 83 cycles of complete refilling or 580 days of operation. Considering a real cost of this device and cost of its replacement without a modification of measuring instrument calibration characteristics such replacement is quite affordable after 1.5 years of operation.

Conclusion

The method of a direct flow measurement with application of a measuring hydraulic cylinder containing a floating piston provides high accuracy of flow rate measurements owing to the application of special hardware and software solutions. It also enables control for fuel consumption at powerful diesel engines. Complete absence from vulnerable components and high level of output signals from sensors applied in this scheme opens the way for its application on boards of powerful transport facilities and provides a high accuracy of volumetric flow control. Application of measuring instruments with accuracy class 0.5 and equipped with measuring cylinders and floating piston has a potential within a range of the volumetric fluid flow from 10^{-2} l/min to 10^{2} l/min.

Different constructions of a a volumetric flow precision measuring instrument were introduced during the Moscow International Salon “ARHIMED 2010” [20] and international exhibition “INVENTIKA 2010” where they were highly appraised by independent international jury.

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