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Original design solution for achieving a liquid density transducer, integratable in the measuring hydraulic circuit of the drum flowmeters

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Are presented the original constructive particularities and performances of a liquids density transducer integratable in the measuring hydraulic circuit of the drum flowmeters. The operating principle of the density transducer is based on the weight variation of a float according to the liquid density where it is immersed.

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1. Introduction

Modern flowmeters must provide high accuracy measurements for a great variety of fluids (mono and polyphasic or binary mixtures) characterized by temperatures, pressures, densities, viscosities, concentration of suspended particles in wide limits and who have different flow regimes (laminar or turbulent, permanent, semi permanent, uniform or not uniform).

Also, according to the environment in which are installed and used, they must be made in normal, explosion-proof, naval or aerospace constructions, benefiting, depending on the case, of adequate mechanical, electrical or climatic protections.

Taking into consideration the above mentioned, the other requirements connected to the nature of the applications they are meant for and also the supplementary demands of the beneficiaries specially on price and reliability we may affirm that it is practically impossible to built such an universal debit meter able to be successfully used in any of the concrete situations involving flow measurements.

Thus resulted a great diversity of constructive types of debit meters each being dedicated to an application aria/field.

In principle the integration of a micro processor in the structure of a measurement system does not overtake its metrological functions but improves them.

A flowmeter with microprocessor is also a flowmeter but with better performances than a classical one and in addition it may be connected in the structure of an automation system controlled by a process computer.

An integrated intelligent flow measurement system, whose block diagram is shown in Fig. 1, incorporates flow, temperature, pressure and density transducers together with auxiliary devices.

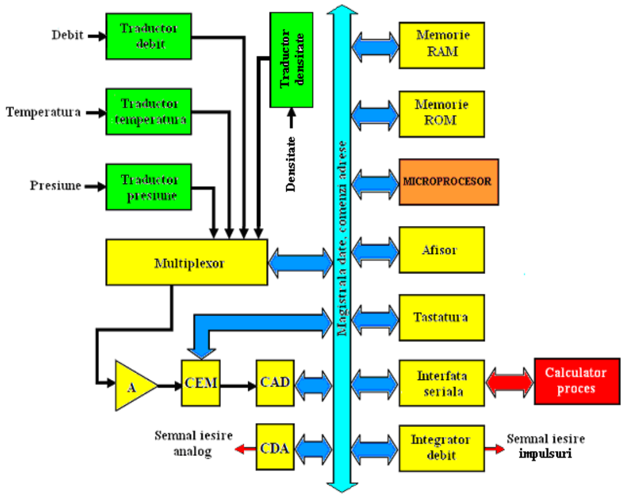


Fig. 1. The structure of integrated intelligent flow measurement systems.

Auxiliary devices are specialized electronic modules controlled by the measurement system microprocessor, which takes over formats and processes the transducers signals and which ensure the correction of the measurement errors due to influence factors, measurement method, zero migration or hysteresis.

Periodically or at the operator demand these devices performs the flowmeter calibration and testing in order to find eventually dysfunctions and provide communication with other devices, equipments or systems within the measurement complex networks.

Based on the algorithm imposed by the used measurement method the programmable microprocessor controls the auxiliary devices functions.

The transducers output signals are overtaken by the electronic module for data acquisition which includes an analogical multiplexer, an operational amplifier (A), a memorizing and sampling circuit (CEM) and a digital analog converter (CAD).

In ROM memory, except the transducers identification codes, are stored the operation program, the correction and linearity tables and instructions afferent to the communication protocol with the process computer.

In RAM memory are stored the current data afferent to ongoing the operating program and data which are going to be sent within the communication protocol. The serial interface provides the flowmeter communication with the process computer or with other devices, equipments, systems to which it is connected by data bus.

The messages sent by the process computer to the flowmeter refers to its configuration, calibration and self testing, while the flowmeter output messages include data on measurement results and realized self tests. The last ones may be visualized by the flowmeter local display and are registered as alphanumeric or graphic forms in database files produced and managed by the process computer.

Additionally, the flowmeter can provide at its output both analog electrical signal (usually voltage or current unified signal) and pulses, of which value respectively frequency varies linearly according to the value of fluid flow. Display control and flowmeter configuration may be realized local by the operator by flowmeter keyboard or by a hand terminal of the process computer.

2. Experimental

2.1 Functional description of the drum flowmeter

The direct volumetric measurement method with drum is used within the discontinuous or slow flowing processes in order to measure the liquid flow rate on the basis of determining the filling time of a measuring chamber.

Ethylic alcohol distillation is the peculiar case of such a process where are used drum flowmeters for on line measuring and integrating the alcoholic liquid flow rate.

These are intelligent integrated systems, see Fig. 2, whose measuring hydraulic system includes, according [1], [2] and [3], the transducers block (BT), the main unit (UC) and electronic modules block for feeding and coupling signal (BMACS).

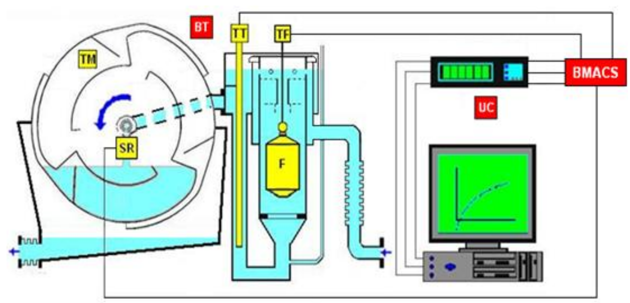


Fig. 2. Block diagram of the drum flowmeter.

The transducers block includes the volume transducer, which is composed of the measuring drum (TM) and the rotation sensor (SR), density transducer, which is composed of the force transducer (FT) and the float (F) and respectively the temperature transducer (TT).

The counting of the consecutive discharges of known volume of the measuring drum compartments, which are highlighted by the rotation sensor, allows the determination of the total liquid alcoholic volume transited through the measuring hydraulic circuit of the drum flowmeter.

Metering the weight of the float, which are total immersed in alcoholic liquid, allows the determination of the density values of the measuring drum discharges volumes and their volumetric alcohol concentration values.

This enables determining the ethyl alcohol volume value contained in the total volume of alcoholic liquid transited through the measuring hydraulic circuit of the drum flowmeter.

The temperature monitoring, realized by means of the temperature transducer, allows appropriate corrections involved by the report all values referred to a preset reference temperature.

The wiring diagram of the drum flowmeter is shown in Fig. 3.

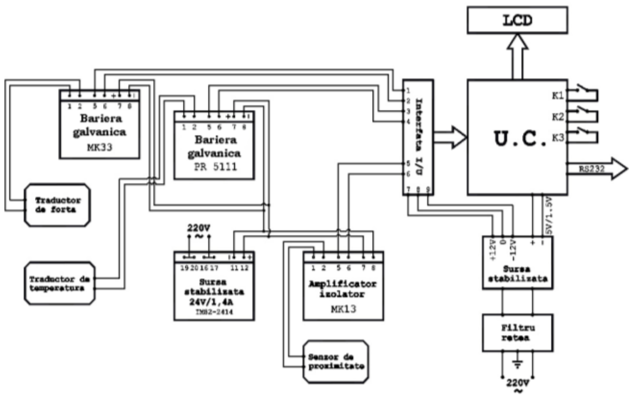


Fig. 3. The wiring diagram of the drum flowmeter.

The main unit processes the drum flowmeter transducers signals in real time and, based of tabulated data taken from [4], [5] and [6], calculates, stores and displays in automatic mode or on operator command, the flow, the temperature, the volume concentration, the density, the total transited alcoholic liquid volume and the volume of ethyl alcohol contained therein.

Flow rates greater than maximum allowable value and temperatures and densities outside the limits of the working ranges are alarmed audio-visual and communicated to the process computer for the purpose of real time adjustments necessary to meet distillation technology.

The central unit ROM memory stored information to identify the main drum flowmeter components (measuring drum, float, temperature transducer, force transducer), the total transited alcoholic liquid volume, ethyl alcohol volume contained therein and dates to which the drum flowmeter was metrology verified or repaired.

ROM memory is secured with password access and can be read and/or inscribed by authorized personnel.

The electronic modules block for power supply and signal coupling consists of two stabilized voltage sources, an isolation amplifier for switching signal and two galvanic barriers for analog signals coupling.

One of the sources provides the 24 Vcc voltages necessary to feed the isolation amplifier and the two galvanic barriers and the other one provides the 5 Vcc and 12 Vcc voltages necessary to feed the main unit and respectively the interface between it and the electronic modules for signal coupling.

The isolation amplifier with and the two galvanic barriers couples to the main unit the switching signal of the rotation sensor and respectively the current unified analog signals of the force and temperature transducers.

2.2. Design and operating theory for the density transducer integrated in the hydraulic circuit of the drum flowmeters for liquids

The density transducer as shown in Fig. 4, includes a force transducer (8) (with elastic sensitive element and resistive strain gauges connected in a Wheatstone measuring bridge), which is suspended a float (6), total immersed in the alcoholic liquid accumulated in the vessel (3), by means of a traction spring (9) and a hook (10).

The alcoholic liquid entered in the measurement hydraulic circuit of the drum flowmeter by connection (1) arrives to the float basin and fills the volume between the walls of the external float basin vessel (2) and float basin (3).

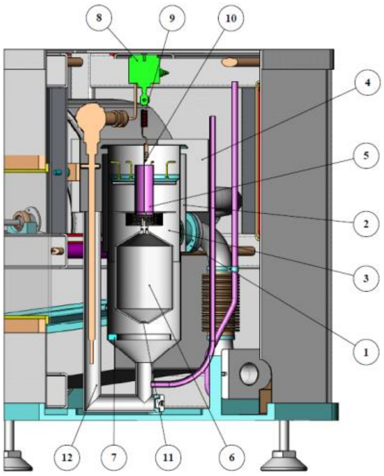
Before overcome in the collector vessel (4), over the edge of the outside float basin vessel (2), a part of the alcoholic liquid goes in the float basin (3) by the circular orifices from the upper part of its wall. The number and the diameter of the orifices limit the stream surface and thus the flow rate of the alcoholic liquid, so that, in the float vessel, should not appear turbulences which may negatively influence the accuracy of the density measurement.

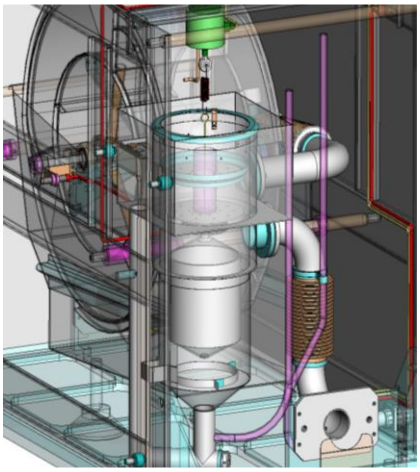
For the same reason is used the stream restrictor (5) composed by a sieves ensemble which supplementary realizes the stabilization of the float balance position till its total immersion.

The alcoholic liquid accumulated in the float basin (3) is then transferred by the draintrap (12) in the collector vessel (4) and by an intermediary elastic connection the liquid flux continues to the measuring drum.

The float spring physically protects the load cell to forces that exceed permissible overload. These may appear if the float vessel is empty or if the float is not completely immersed in the alcoholic liquid. The spring is designed so that, to the permissible overload, his extension allows the float supporting on its fulcrum.

The lead shot (11) placed inside the float are meant to move as low as possible its weight center in order to provide a stable balance in the liquid stream and respectively for adjusting the float mass to adapt it to measurement interval of the force transducer.





1. Inlet connection float basin	7. Float fulcrum
2. External float basin vessel	8. Force transducer
3. Float basin	9. Float spring
4. Collector vessel	10. Float hook
5. Stream restrictor	11. Lead shot
6. Float	12. Draintrap

Fig. 4. The constructive solution adopted for achievement of the density transducer with float integratable in the measuring hydraulic circuit of the drum flowmeters.

The volume and mass of the float are measured in laboratory conditions with a high level accuracy [7].

The float is made of food stainless steel sheet metal, has a central cylindrical body with two conical caps and is sealed at the top with an eyelet bolt, which allows its hanging. On top of the eyelet bolt is enrolled the float identification code according to the requirements stipulated in [1].

Depending on the volume concentration of the binary solution of water and ethyl alcohol, the float weight, determined as the difference between its absolute weight and the weight of the fluid displaced by the totally immersed float, shall be changed accordingly, resulting at the output of the force transducer an current unified electrical signal, whose value varies depending on the value of the alcoholic liquid density. This signal is coupled by a dedicated galvanic barrier to the central unit of the drum flowmeter and processed.

Density estimation, d_i, of the alcoholic liquid volume evacuated by one of the measuring drum compartments, determined as the arithmetic average of m density estimations, d_{i_n}, measured at intervals of 2 seconds in the period of time, T_{dctm}, between two consecutive discharges of the measuring drum, is calculated using the relation:

$$d_i = \frac{1}{m} \cdot \sum_{n=1}^{m} d_{i_n} \tag{1}$$

m: the integer part of the ratio $T_{dctm}/2$.

Density estimations, d_{i_n}, is calculated using the relation:

$$d_{i_n} = \frac{m_{afl} \cdot g - G_{fl_{im}i_n}}{V_{fl} \cdot g} \tag{2}$$

m_{afl}: the conventional true value of the float absolute mass,

$G_{fl_{im}}i_n$: n estimation of the weight of the float immersed in alcoholic liquid with the density, d_{i_n},

V_{fl}: the conventional true value of the float volume,

g: the local value of the gravitational acceleration.

The force transducer has a sturdy construction which gives it reliability and durability in aggressive environments. Its elastic sensitive element, made of an aluminum alloy with a very good tenacity, is deformed like a parallelogram mechanism, case where the weighing pan moves parallel to itself, making it possible the application of the off-centre loads without negatively influencing the measurement accuracy.

Supplementary, the force transducer includes an electronic circuit for calibration and remote verification of its functionality and a current amplifier with gain and zero adjustments, which provides insensibility to external electromagnetic perturbations. All electronic circuits of the force transducer and their associated connections are encapsulated in waterproof silica gel and rubber to ensure protection against vapors and condensate.

The electronic modules block for power supply and signal coupling of the drum flowmeter includes a dedicated galvanic barrier for analog signal to the power supply and transfer the current unified signal of the force transducer from the potentially explosive in the normal environment to the main unit, with intrinsic protection and total galvanic isolation between in/out active type and the power supply circuit.

In order to determine V_{fl} and m_{afl} have been determined, by weighing in air and respectively in distilled water, the corresponding masses, $m_{fl_{aer}}$ and $m_{fl_{apa}}$, of the float of the density transducer with the absolute admissible indication error specific to the laboratory balance used for this purpose, ε_m.

Using calculation tables in conformity of [4] and [5], are determined the conventional true values of the air density, ρ_{aer}, and distilled water, ρ_{apa}, according to the pressure, temperature and relative humidity values, specifics to the laboratory environment at the moment when have been done the weighings.

The conventional true value of the float volume is calculated using the relation:

$$V_{fl} = \frac{m_{fl_{aer}} - m_{fl_{apa}}}{\rho_{apa} - \rho_{aer}} \tag{3}$$

The value of the absolute admissible indication error of the conventional true value of the float volume is calculated using the relation:

$$\varepsilon_{V_{fl}} = \frac{4 \cdot \varepsilon_m}{\rho_{apa} - \rho_{aer}} \tag{4}$$

$m_{fl_{aer}}$: the conventional true value of the float mass in air, measured with indication absolute admissible error, ε_m,

$m_{fl_{apa}}$: the conventional true value of the float mass in distilled water, measured with indication absolute admissible error, ε_m,

ρ_{aer}: the conventional true value of the air density,

ρ_{apa}: the conventional true value of the distilled water density, measured in standard temperature atmospheric pressure and relative humidity conditions.

The conventional true value of the float absolute mass is calculated using the relation:

$$m_{afl} = m_{fl_{aer}} + V_{fl} \cdot \rho_{aer} \tag{5}$$

The value of the indication absolute admissible error of the conventional true value of the float absolute mass is calculated using the relation:

$$\varepsilon_{m_{afl}} = \varepsilon_m + \varepsilon_{V_{fl}} \cdot \rho_{aer} \tag{6}$$

The value of the indication absolute admissible error of the conventional true value of the n estimation of the weight of the float, $G_{fl_{im}n}$, immersed in alcoholic liquid with the density, d_{i_n}, is calculated using the relation:

$$\varepsilon_{G_{fl_{im}n}} = \varepsilon_{tf} \cdot G_{fl_{im}i_n} \tag{7}$$

ε_{tf}: the indication relative admissible error of the force transducer included in the density transducer of the drum flowmeter.

The value of the indication absolute admissible error of the density estimations, d_{i_n}, is calculated using the relation:

$$\varepsilon_{d_{i_n}} = max \begin{bmatrix} \frac{\left(m_{afl}+\varepsilon_{m_{afl}}\right)\cdot g - G_{fl_{im}i_n} + \varepsilon_{G_{fl_{im}i_n}}}{\left(V_{fl} - \varepsilon_{V_{fl}}\right)\cdot g} - d_{i_n} \\ d_{i_n} - \frac{\left(m_{afl}-\varepsilon_{m_{afl}}\right)\cdot g - G_{fl_{im}i_n} - \varepsilon_{G_{fl_{im}i_n}}}{\left(V_{fl}+\varepsilon_{V_{fl}}\right)\cdot g} \end{bmatrix} \quad (8)$$

Now may be determined the value of the indication absolute error ε_{d_i}, of the density estimation, d_i, of the alcoholic liquid volume discharged by one of the measuring drum compartments being equal to the maximum value of $\varepsilon_{d_{i_n}}$:

$$\varepsilon_{d_i} = max\left\{\varepsilon_{d_{i_n}}, n\epsilon[1; m]\right\} \quad (9)$$

For the density interval, [0.7895 ÷ 0.9820] g/cm^3, specific to the analyzed application, where the density transducer is incorporated in the measuring hydraulic circuit of the drum flowmeter for measurement and integrate in real time the alcoholic liquid flow rate, the value of the value of the indication absolute admissible error of the density, d, is equal to the maximum value of ε_{d_i}:

$$\varepsilon_d = max\{\varepsilon_{d_i}, d_i\epsilon[0.7895;\ 0.9820]\} \quad (10)$$

3. Results and discussions

As a result of the laboratory determinations and using relations (3) and (5), have been obtained the following conventional true values of the volume and respectively of the absolute mass of the density transducer float:

$$V_{fl} = 1060{,}96\ [cm^3]$$

$$m_{afl} = 1156{,}27\ [g]$$

With relations (2), (4), (6÷10) are determined the indication absolute admissible error value of density, d, of the alcoholic fluid which characterizes the measurement made with this type of density transducer:

$$\varepsilon_d = 0.0002\ \left[\frac{g}{cm^3}\right]$$

On the one hand, this very good measurement accuracy of the density transducer with float is due to the small measurement uncertainty, ε_m, of the laboratory balance utilized for weighing in air and in distilled water the float of the density transducer,

$$\varepsilon_m = 0{,}0002\ [g]$$

and by the adder hand, of the low relative admissible indication error, ε_{tf}, of the force transducer from its composition,

$$\varepsilon_{tf} = 0.05\ [\%]$$

obtained as a result of its static very accurate calibration performed strictly for the densities working range of the density transducer with float:

$$[0.7895 \div 0.9820]\ \left[\frac{g}{cm^3}\right]$$

In Fig. 5 is shown the variation graphic of the absolute indication error value, ε_{d_i}, of density estimation, d_i, of discharged alcoholic liquid volume by one of the measuring drum compartments.

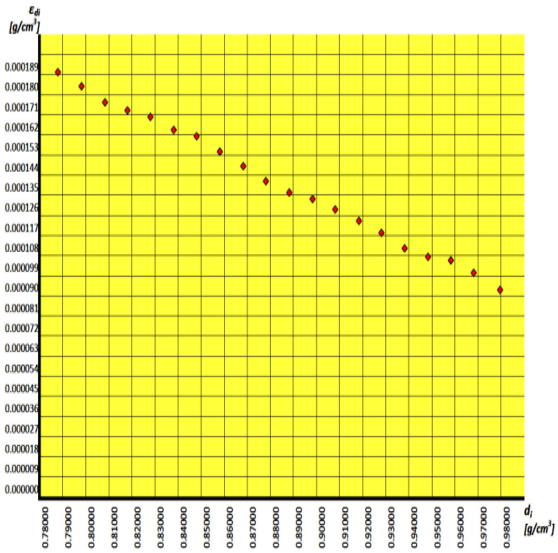


Fig. 5. The variation graphic of the absolute indication error value, ε_{d_i}, of density estimation, d_i.

An important advantage of the density transducer with float integrated in the measuring hydraulic circuit of the drum flowmeters is that it may be used within the discontinuous or slow flowing processes that take place at small pressure and even in partially filled pipe, opposite to the other type of densimeter which operating on the vibrant element principle (based on the dependence between resonance frequency of some mechanical systems in oscillatory movement and the liquid density which transits or in which they are immersed), on the optical principle (spectrophotometric) or the ultrasonic principle and which are characterized by inferior measurement uncertainties.

4. Conclusions

The drum flowmeter for in real time measuring and integrating flow rate of the alcoholic liquid transited on the productions lines of the ethyl alcohol distilleries equipped with density transducer with float represents a viable and actual alternative to the measurement systems having the same destination, products in the country or abroad, under the conditions of a free market, none of the legal measuring devices of the volume and concentration of the alcoholic liquid having MID certification.

The excellent balance between measurement accuracy and price, high reliability and small expenses involved in maintenance and service activities, recommends the density transducer with float as a very competitive measuring device on the afferent market of its domain of application.

The constructive solution adopted for achieving the density transducer with float is original and will be in the nearest present the subject of a patent request.

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