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Primary Analysis of Effective Permeability of the Flame in Burning Natural Gas

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Abstract

This paper presents a method of analysis of effective permeability of the flame in burning natural gas. In order to conduct a complex analysis, it is necessary to determine this parameter as a special case of the process of quasi-plasma nature for the purpose of investigating the options for application of suitable industrial methods applied in similar cases. We observed the synergy of solenoid parameters of the plasma part of the flame with ceramic materials without any special additional customization of the measurement device. The processed results of measurement demonstrate additional requirements necessary for measurement technology. The method was applied for various cases of energy of pulse signals and for two types of finalized sensors. The method uses a definite marker in observed voltages, which is realized after exceeding the gate voltage in the forward direction of the fast semiconductor valve. Results of measurement show that the values of effective permeability can be measured via this method with acceptable sensitivity.

Key words : Effective permeability, Properties of flame, Natural gas

Introduction

Measurement of ionization of the flame which was published in[1] shows that the first operations for describing the natural gas flame can be carried out also for further parameters of the quasi-plasma nature of the flame. Properties of arc excitation and high-temperature applications such as devices for plasma breakdowns in publications[2-4] or special plasma applications for furnaces[3, 4] are all subject to Sach's law. [5-7] Extreme cases were examined in the past for devices of type Tokamak but quasi-plasma non-arc excitation was not examined because from the energy perspective, aside from generation of heat, it did not have any special application. Sach's law is usable for measurement of the degree of ionization only while using a modified approximation. Therefore, examination of further properties of the natural gas flame is important in this context as well. Measurement of the flame for temperatures up to 1700˚C can be accomplished even in laboratory conditions and thus it is possible to predict the properties of the flame almost up to arc excitation. The method was focused on stating the effective permeability of the natural gas flame in the first approximation.

Theoretical Basis

By introducing the flame into a system of solenoids, the flame is manifested as a solenoid parameter and in a favorable case, a feedback manifesting itself in the change of self induction, or respectively, in the change of mutual induction, which characterizes the coupling to the secondary system. If we direct the flame in the axis of the solenoid, the influence derived from the theory of the electromagnetic field, is mainly of magnetic nature, because the intensity of the electric field generated by self induction processes in the solenoid's axis is zero. As far as the inner side of the solenoid, values of both intensities are comparable. Therefore, in case of using a solenoid skeleton made out of cemaric material with $\varepsilon_r > 1$, for a given range of frequencies, one can expect a synergic effect of the impact on the solenoid. It is advantageous to minimize all parasitic reactions in the measurement parimeter of the excitation generator in such a way that the properties of the measurement sensor dominate. Then, all relaxation times will depend on the value of the energy of the impulses and reactance properties of the solenoid. The process of marking of the course of discharging the solenoid's energy takes place after

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completion of the relaxation process by physically reversing the direction of the current flowing through the solenoid via blocking the current on the edge of non-linearity of the fast semiconductor diode. The location of the marker in the course of the voltage when using a long enough discharging period allows finding the change of induction even at small relative changes.

Chosen Methods of Processing

To conduct the measurement, a circuit as per Figure 1 was used. At zero input, the generator's internal resistance is infinitely large. Period of 47μs was used, with pulse width of approx. 1.5 μs. The generator had these properties at the resistance load. In Figure 1, values R of the resistor were used such that a voltage limitation would not occur and so that limitation would occur for the purpose of increasing the energy of the pulses.

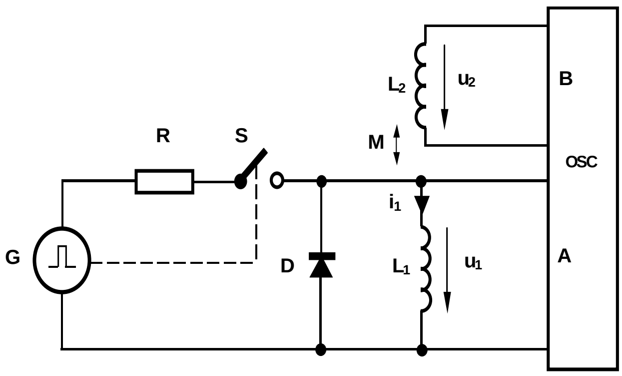

Figure 1. Measurement circuit

For current $i_1(t)$ within the circuit, the following holds:

$$i_1(t) = R^{-1} \cdot [U - u_1(t)] \qquad [\mathrm{A}] \qquad (1)$$

where $u_1(t)$ and $i_1(t)$ are voltage and current of the primary solenoid (L_1) a R is the limiting resistor in the perimeter of the generator as per Figure 1. The following relation holds for ratio p of the transformation system according to Figure 1

$$p = \frac{u_1(t)}{u_2(t)} = -\frac{R \cdot u_1(t)}{M \cdot \left[\frac{du_1(t)}{dt}\right]} \qquad [\text{ - }] \qquad (2)$$

Where $u_2(t)$ is the course of the voltage on the secondary solenoid L_2. From the defining relations for circuit elements of a system with mutual feedback inductance M, the following equation is obtained:

$$\frac{u_1(t)}{L_1} = \frac{du_1(t)}{dt} = \frac{u_2(t)}{M} \text{ because } \frac{di\ (t)}{dt} = -\frac{1}{R} \cdot \frac{du_i(t)}{dt} \qquad (3)$$

For general course of voltages $u_1(t)$ and $u_2(t)$, we then obtain

$$p = \frac{u_1(t)}{u_2(t)} = \frac{L_1}{M} \qquad [\text{ - }] \qquad (4)$$

If we use Nagaoka's coefficients for describing inductances L_1 and L_2 using α_1 a α_2, at n_1 a n_2 of coil turns we will use an alternative expression of the value of inductance

$$L_1 = \mu \cdot \alpha_1 \cdot n_1 \ [\mathrm{H}] \text{ and } L_2 = \mu \cdot \alpha_2 \cdot n_2 \ [\mathrm{H}] \qquad (5)$$

where μ is absolute coil-permeability. Inductances are chosen so that the relaxation process takes place in the gaps between impulses. Typical course of the voltage and current on the primary solenoid is depicted in Figure 2 Without the presence of a flame, expression of the secondary voltage $u_2(t)$ is identical to that of $u_1(t)$.

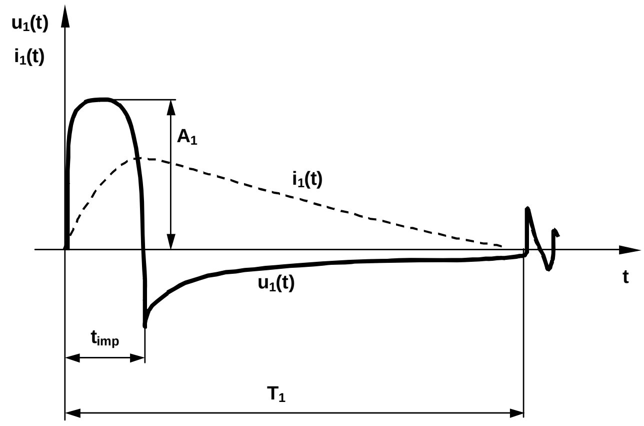

Figure 2. Relaxation process

After disconnecting the semiconductor valve S, voltage on the inductance decreases into negative values, while the direction of the current with inductance L_1 does not change even after disconnecting the generator. The discharging phase during the time period T_1 is done via diode D and ends with the first marker of relaxation on the nonlinear part of the diode's transition. For small differences in value T_1 before and after application of the flame, it is possible to use the relations for the ratio between inductance with the flame L_{1P} and without the flame L_1 in the explanation of the response to the signal with a functionally defined course or for harmonic signal. Then, it can be claimed that:

$$\frac{L_{1P}}{L_1} = \mu_P = \frac{-R \cdot \dfrac{u_{1P}(t)}{\dfrac{du_{1P}(t)}{dt}}}{-R \cdot \dfrac{u_1(t)}{\dfrac{du_1(t)}{dt}}} = \frac{2 \cdot \pi \cdot \omega_1}{2 \cdot \pi \cdot \omega_{1P}} \approx \frac{T_{1P}}{T_1} \quad [-] \qquad (6)$$

where μ_P is the sought effective relative permeability of the flame.

In relation (6), we have set for the Laplace transform in case of a harmonic course p = jω and substituted relations (1) to (5) . If we denote the amplitudes of the voltage pulses A_1 a A_2 for $u_1(t)$ and $u_2(t)$, then using expression (4), it is possible, without any loss to the generality of the relation, to state:

$$\frac{M_p}{M} = \mu_P \cdot \frac{A_{2P} \cdot A_1}{A_{1P} \cdot A_2} \quad [-] \qquad (7)$$

where M_P and M are mutual feedback inductance and this value without flame,

A_{2P} and A_{1P} are secondary voltage amplitude with flame on the coil L_2 and L_1,

A_2 and A_1 are secondary and primary amplitude without flame.

Evaluating Results of the Measurement

Results of the measurements obtained using relations (1) to (7) are summarized in Table 1. Results were obtained based on processing oscilloscopic data (Tektronix TDS 210).

Table 1.

PROBE	IMPULSES	T_{1P} [μs]	T_{1P} [μs]	M_P/M [-]	μ_P [-]
CERAMICS	**SATURATED**	8.75	7.00	1.328	1.250
	NOT SATURATED	14.00	13.75	1.077	1.018
AIR-COIL	**SATURATED**	11.00	10.62	0.970	1.035
	NOT SATURATED	13.25	12.95	0.985	1.023

From Table 1, it is evident that in case of self-supporting air-cored coils, the values of the effective permeability of the flame is μ_P within an interval <1.023 ; 1.035 > [-] and in case of a sensor with a ceramic tube, is μ_P within an interval <1.018 ; 1.250 > [-], depending on the energy of the pulse. The result with the ceramic tube illustrates synergy of ceramics. Figure 3 shows an example of a typical course from an oscilloscope recording obtained when using a generator constructed for a laboratory experiment.

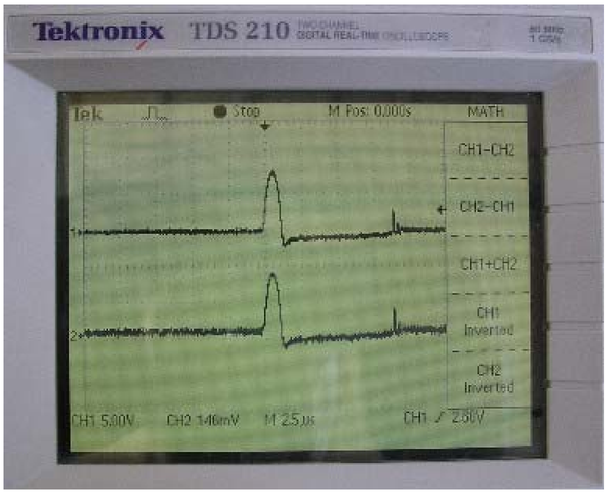

Figure 3. Sample of the measured process

Conclusion

Results of the effective measurement point out the fact that for further analysis, it will be necessary to use an oscilloscope with a significantly higher frequency range (up to 10 GHz). Measured values of the effective magnetic permeability of the flame are measurable with satisfactory sensitivity and favorable. Synergy of the ceramics was also confirmed for solenoid parameters of the measurement sensor.

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