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Measuring of Solid Phase Concentration In Aqueous-Cellulose Pulp Using Microwave Sensors

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ABSTRACT: We present the serial microwave sensors, intended for measuring ground cellulose-paper mass concentration in composition of paper-aqueous pulp, which is a source raw material for paper manufacture. The basic physical principles of application of such sensors and their design are described.

KEYWORDS: Paper-aqueous pulp, Measuring of mass concentration, Microwave sensor.

I. INTRODUCTION

Paper-aqueous pulp is a source raw material for paper manufacture. It is made in grinders, where cellulose-containing fiber materials undergo milling in the presence of water before coming on continuous fabric loop of a papermaking machine [1–4]. The quality of obtaining paper materials is determined to a considerable extend by concentration of cellulose material in this pulp. A grinder operates more economically only at that mass concentration, for which it is assigned. Such optimal concentration is 5–6 % for rolls of periodic operation, 4–5 % for hydrofiners, 3–3.5 % for conical Jordan's mills and 4–5 % for disk rafiners [1–3]. Reduction of mass concentration relatively its optimal value causes decrease of fibers interlayer thickness between knifes of a grinder and then, in consequence fibers undergo more strong cut effect from knifes. As a result, the fibers become too short and less hydrated, what leads to deterioration of quality of fabricated paper. Regularity of paper mass concentration is a necessary condition for providing normal operation of a papermaking machine and of homogeneous and high-quality paper manufacture. That is why at paper production, one pays great attention to exact control and stabilization of solid-phase concentration in the paper-aqueous pulp at various stages of the technological process. Besides, such control provides decrease of utilizing water volume, what is very important for ecology, because the paper and pulp industry consumes enormous quantity of water actually in comparison with another brunch of modern industry. In this paper, we present microwave sensors of concentration of paper material in aqueous suspensions, designed for needs of pulp and paper industry. Here, the basic physical principles of microwave sensors operation and its design are considered.

II. MATERIALS AND METHODS

Various types of industrial devices for measuring cellulose concentration in pulp are produced in the world, whose operation is based on different physical principles (see, for example, [1–4]). They use mechanical interaction of moving (swimming, gliding, rotating) elements with cellulose suspension, changing of optical characteristics of microwave, infrared or optical radiation at passing through or reflecting from the substance, and also various laboratory techniques: pressing, drying or combination of both. Laboratory methods are the most exact and can serve as the standard ones for another techniques, but they are low-productive and cannot be realized at continuous technological regimes. Mechanical methods are characterized by substantial deficiencies, such as low accuracy of measurements, unreliability and fragility. It is difficult to preserve stable conditions of mechanical interaction between suspension and the pickup of a sensor. The other deficiency of mechanical detectors is caused by continuous soiling of that and by necessity of its regular servicing. Optical transmission sensors can operate well only at low fibers concentration and at small base

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length between a radiator and a receiver. This type of sensors is characterized by high sensitivity to optical channel clogging. Using regime of reflection operation, one can test the pulp of more high cellulose concentration, but and here sensitivity to clogging remains also very high.

The microwave technique is presented as optimal for measuring cellulose concentration in pulp, because it has such advantages as absence of mechanical elements, hindering pulp moving, and low losses of that in the microwave range. For this range, the losses decrease under increase of solid state concentration, whereas for mechanical and optical sensors the inverse situation takes place. The given circumstance provides the opportunity to apply this method at high concentrations using long distances between a radiator and a receiver. This decreases measurement errors and also depresses the danger for pipeline walls and sensor windows to be clogged. These advantages are preferable for operation under difficult conditions of paper and cardboard manufacture from waster-paper mass.

III. BASIC PHYSICAL PRINCIPLES OF MICROWAVE SENSOR OPERATION

The principle of operation of a microwave sensor is based on the following. If dielectric material is placed between two radiators, one of which is connected with input of a microwave amplifier, and the other is connected with its output, then self-excited oscillations can arise in such a system [5]. The condition of their appearance is coincidence of the oscillation phases at input and output radiators

$$\mathrm{Re}\, kL = 2\pi N$$

where k is the complex wave number of oscillation (complexity of this value takes into account possible attenuation of oscillations in time), L is the distance between radiators, N=1,2,3,… is an integer. Let us take into consideration that a real part of the wave number is expressed in terms of the frequency f and the wavelength λ of electromagnetic oscillations

$$\mathrm{Re}\, k = 2\pi f n/c = 2\pi n/\lambda$$

(n is the effective refractive index of a medium, c is the velocity of light). Then the frequency of arising self-excited oscillations is determined by the expression

$$f = Nc/nL \qquad (1)$$

with the corresponding wavelength

$$\lambda = nL/N$$

If the space between radiators is filled by a homogeneous medium with the complex dielectric permittivity

$$\varepsilon = \varepsilon' + i\varepsilon'' = (n + i\kappa)^2 \qquad (2)$$

(κ is the index of absorption), then the effective refractive index of this medium equals

$$n = \sqrt{\frac{\sqrt{(\varepsilon')^2 + (\varepsilon'')^2} + \varepsilon'}{2}}$$

It follows from (1) that generation is possible at any frequency, which is divisible by $f_0=c/nL$. Consequently, at wide excitation band, a set of self-oscillations with various frequencies (1) are excited in an oscillating system, what causes ambiguity in determining of physical parameters of a dielectric under test with the help of such a system. To overcome this difficulty for wide frequency band of transmitting field, one can use a band filter, transmitting radiation in very narrow band. Radiators itself can be such filters, if they have resonance characteristic with a particularly pronounced minimum of attenuation.

Matching of an aerial-radiator with medium does not cause difficulty only at the case, when losses in a medium are not great, and the field in the near zone is not subject to perturbations. In water, medium losses reach the value of 1

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db/cm at frequencies from 1 up to 2 GHz, therefore, to match a radiator with such a medium is not a simple problem. To overcome this difficulty, on can apply various matching structures, for example, artificial dielectrics. Computation of such structures is carried out usually for one frequency only and it is very approximate, that is why empirical features predominate in designing of such devices [5].

We have selected a coaxial-waveguide transition (CWT) as a radiator for a concentration measure, because it displays resonance behavior. Being matched with a coaxial line and partly mismatched with a medium, such a radiator accumulates energy, reflected from interface. As a result, part of energy is radiated, and the other part is recovered in CWT, creating the structure of field like that in a cylindrical cavity resonator, because dimensions of CWT conform to its frequencies of self-excitation. At that, one observes comparatively great width of every resonance line corresponding to separate eigen-frequency of a system “radiator-medium”, what is due to high losses in that and is concerned with low quality factor of a system.

In our device, the cellulose fibers concentration is determined by measuring of frequency of self-excited oscillations in a suspension between a radiator and receiver. The dielectric permittivity of a mixture can be determined in terms of the values of effective refraction and absorption indexes (Equation (2)). These indexes are determined according to (1) as follows

$$n = \frac{Nc - f L_e}{f L}; \qquad \kappa = \frac{\tau}{L} \tag{3}$$

where L_e is the equivalent length of electric transmission line, τ is the index of exponential decay of electromagnetic oscillations over the total path from a radiator to a receiver. Thereby, measuring the frequency f and the index of decay τ in a system, one can determine the fiber concentration in a suspension.

Resulting equation for computation of concentration C, which can be derived on the bases of general physical considerations [6], is rather lengthy. However, one should take into account that weight concentration of fibers in suspensions is comparatively small and usually not exceeds the value of 5 %. In this case, one gives approximately a linear dependence of dielectric permittivity on the volume concentration v and correspondingly, on the weight one C. Taking into account this circumstance, we can write the linear equation for the frequency of self-oscillations as a function of concentration C

$$f = \alpha C + \beta T + \gamma CT + \sigma \tag{4}$$

where α, β, γ, σ are the constant values, determined immediately from experimental data. Linear dependence on temperature T, declared by equation (4), is confirmed by practical measurements. At any rate, in the temperature range from 5 up to 50º C, this equation yields satisfactory results.

IV. THE SENSORS DESIGN

In actual practice, one should take into account that the dielectric permittivity of water highly depends on temperature [7]. For example, at frequency near 1.5 GHz, change of 1°C in temperature results the measured value of cellulose concentration in error of 0.25 %. That is why a precise quartz thermometer is used in a concentration sensor for compensation of the suspension temperature effect. Just one more negative factor is the influence of water conductivity on its effective dielectric permittivity (Equation (2)), what specially displays under operation of a concentration sensor with waster-paper mass. In this case, one should take into account conductivity of water, using a conductivity sensor, contacting with a suspension passing through a pipeline. Compensation of all negative factors, affecting on the concentration measuring process, and using of microprocessor technique, provide the opportunity to produce microwave concentration sensors having the following characteristics

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(a)

(b)

Fig. 1. Microwave sensors of concentration of paper mass in a water-paper pulp "A-343" (a) and "A-344" (b)

Microwave sensor “A-343” (Fig. 1a)

Accuracy of measurements in magnitude	<0.02 %
Concentration measuring range	0–8 %
Temperature of the process	+5–70°C
Temperature of environment	+0–50°C
Conductivity of medium, max	15 mS/cm
Pressure in pipeline	150–1000 kPa
Flow speed	<4 m/s
Diameter of pipeline	≥200 mm
Output	4–20 mA
Communication	RS-232, RS-485
Protection degree	IP 65
Power	100–260 V, 25 VA

Microwave sensor “A-344” (Fig. 1b)

Accuracy of measurements in magnitude	<0.02 %
Concentration measuring range	0–6 %
Temperature of the process	+5–60°C
Temperature of environment	+0–50°C
Conductivity of medium, max	10 mS/cm
Pressure in pipeline	150–600 kPa
Diameter of pipeline	150 mm
Output	4–20 mA
Communication	RS-232, RS-485
Protection degree	IP 54
Power	100–260 V, 25 VA

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These characteristics satisfy all technical requirements for pulp and paper industry and provide high accuracy and stability of measurements during long-time continuous cycle of paper-making process. In fact, these two types of sensors differ one from the other by the diameter of pipeline, for which a sensor is suitable. Whereas the sensor "A-344" (Fig. 1b) is gauged for pipeline of pulp supply with relatively small diameter of 150 mm, the sensor "A-343" (Fig. 1a) can be used in pipelines having greater diameter. Fig. 2 demonstrates schematically operation of these sensors in composition of pipelines and displays difference between them (because of too great magnitude of the dielectric permittivity of pulp and of short distance of propagation, one does not observe diffraction divergence of microwave radiation inside that). Because of the presence of losses in paper-aqueous pulp for the microwave region of electromagnetic waves, it is expedient to make the distance for testing radiation not very long. That is why the sensor, placed in a pipeline of great diameter, has a special metallic reflector, which is attached to a measuring block and is introduced into a pipeline (see Figs. 1a and 2a). At that, one can test only a part of the flow inside that, but owing to such design, the same sensor can be used in pipelines of various diameter.

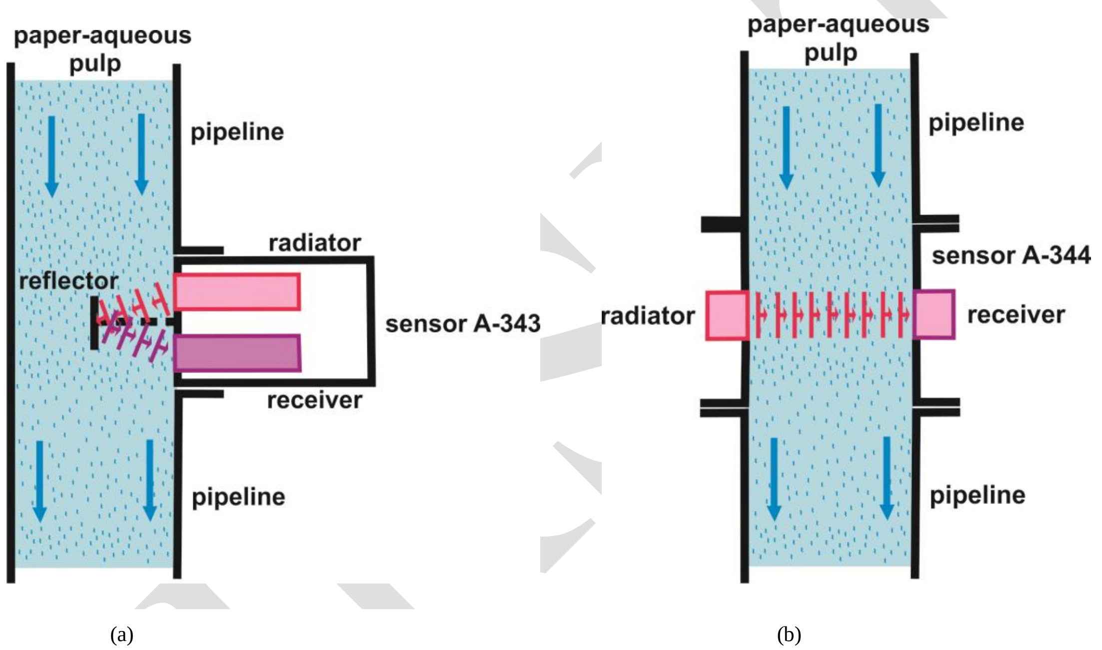

Fig. 2 Schematic view of operation of the microwave sensors in composition of pipeline of paper-mass supply "A-343" (a) and "A-344" (b).

In design, a concentration sensor consists of a measuring block, which is placed on a pipeline, and an indication block (Fig. 1). The first one contains a radiator and a receiver of microwave radiation, sensors of temperature and conductivity of paper mass, and also microprocessor module, designed for determining of the dielectric permittivity of paper mass in view of its temperature and conductivity. This module serves for computation of concentration and for transmission of measured data to an indication block. This block is intended for receiving data from a measuring one, displaying running values of concentration, temperature, conductivity, for forming of trends of measuring values and also for input of tuning coefficients.

Fig. 3 shows the general view of the sensor "A-344" embedded into a pulp-supplying pipeline. Here, one can see the method of sensor holding on a pipeline (dark-blue color) and its different blocks (red color).

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Fig. 3. The microwave sensor "A-344" in composition of pipeline

IV CONCLUSION

Application of microwave method is very effective for measuring solid phase concentration in water-paper pulp. This method has been realized by developing a whole family of sensors intended for paper industry needs. These sensors can be embedded into technological line of pulp supply on a paper-making machine and operate in real time during all technological process. Besides of high accuracy of measurement of solid phase concentration, such devices are not sensitive to the kind of paper fibers, to their length, to composition, grade, colour, speed of flow, and they are especially indispensable for concentration measurements in waster-paper mass flows. Our experience shows that the field of application of these devices is not restricted to paper-aqueous pulp and they can be used for measuring solid-phase concentration in various aqueous suspensions and liquid flows including sewage. High quality of given devices is confirmed by the fact that more than 150 such sensors have been delivered and now operate in pulp and paper enterprises of Belarus, Russia, Kazakhstan, Ukraine and Lithuania.

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BIOGRAPHY

Josef A. Titovitsky was born in Grodno district, Belarus, 1953. He received the Diploma and the Candidate of Sc. (Ph.D.) degree from the Belarusian State University, Minsk, Belarus, in 1974 and 1985, respectively, both in radiophysics. From 1974, he works in the Institute of Applied Physical Problems of the Belarusian State University, now he is head of a laboratory of this institute. His main activities are in the field of study of heterogeneous materials, development of nondestructive sensors and automatic control systems for various brunch of industry.