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MEASUREMENT OF THE ELECTRICAL QUANTITIES OF THE WET SCRUBBER
MERENJE ELEKTRIČNIH VELIČINA VLAŽNOG FILTERA ZA VAZDUH

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ABSTRACT

With the aim of reducing environmental, energy and quality problems in the field of farming of animal species, laboratory for agricultural technique in animal husbandry, Department of Agricultural Engineering, Faculty of Agriculture, University of Novi Sad, integrally develops a system for wet air purification, wet scrubber, and its energy control. The goal of electrical measurements in a wet scrubber is to determine instantaneousand interval-accurate values of electrical quantities, defined by physical methods. Devices for electrical measurements give precise values of basic electrical quantities: current, electromotive force, voltage, impedance, electrical work, power, and energy. Simple periodic voltages and currents are crucial for wet scrubber drive elements. They are determined by three quantities: amplitude, frequency, and phase. The paper presents the basic patterns for the measured values of wet scrubber drive elements: AC operation, AC power, AC power with active resistances in the circuit and AC power with impedance in the electric circuit. The presence of many drive elements for partial operational actions in a wet scrubber is the basic reason for choosing a central atomizer, as the object of methodologically original energy analysis of this work.

Key words*: air, wet filter, current, voltage, impedance, power, measurement.*

REZIME

Sa ciljem redukcije ekoloških, energetskih i kvalitativnih problema na polju farminga životinjskih vrsta, laboratorija za poljoprivrednu tehniku u stočarstvu, Departmana za poljoprivrednu tehniku, Poljoprivrednog fakulteta, Univerziteta u Novom Sadu, integralno razvija sistem za vlažno prečišćavanje vazduha (VFV), i njegovu energetsku kontrolu. Cilj električnih merenja u VFV-u je određivanje trenutno i intervalno preciznih vrednosti električnih veličina, fizičkim metodama definisanih. Uređaji za električna merenja daju precizne vrednosti osnovnih električnih veličina: jačina struje, elektromotorne sile, napona, impedanse, električnog rada, snage i energije. Za pogonske elemente VFV-a presudni su prostoperiodični naponi i struje. Prostoperiodični naponi i struje određeni su sa tri veličine: amplituda, frekvencija i faza. U radu su izvedeni bazni obrasci za merene veličine pogonskih elemenata VFV-a: rad naizmenične struje, snaga naizmenične struje, snaga naizmenične struje sa aktivnim otpornostima u kolu i snaga naizmenične struje sa impendansom u električnom kolu. Zastupljenost većeg broja pogonskih elemenata za parcijalne operativne radnje u VFV-u, bazni je razlog izbora centralnog raspršivača, kao objekta metodski originalne energetske analize ovog rada. Za sveobuhvatnu realizaciju zahtevnih električnih, kinematičkih i dinamičkih merenja, obezbeđeni su merni instrumenti: trofazno električno brojilo za reaktivnu energiju, referentno trofazno brojilo za potrošnju aktivne električne energije, niz lokalnih trofaznih i monofaznih brojila, šest digitalnih brojila za merenje napona, struje, potrošnje električne energije i faktora snage ***cosφ****, univerzalna strujna klešta DC/AC, digitalni multimetar/oscilograf, beskontakto-kontaktni merač broja obrtaja, digitalni stroboskop, više raznovrsnih unimera, itd.*

Ključne reči: *vazduh, vlažni filter, struja, napon, impendansa, snaga, merenje.*

INTRODUCTION

Obviously, as the basis of links in the nutrition of the human population, breeding of animal species on a global scale becomes one of the bad weapons for its tendentious reduction. The basic reason for this is ecology in confrontation with a significant share of alternating electrical energy, as an extreme input of growing cycles. In fact, animal husbandry carries the label of a significant air polluter (*Gustafsson, 1988., Jeppsson, 2000*), with frequent reports of concentrations exceeding recommended exposure limits (*Peters et al., 2012; Reeve et al., 2013; Anthony et al., 2017*). At the top of the list of contaminants in the air of breeding facilities are dust and gaseous components: NH_3, H_2S and CO_2 (*CIGR, 1999*) gaseous of components. Absorption of components in moistened dust is an ideal bed for the development of pathogens (*CIGR, 2002*), which negatively affects the health, reproducibility, and productivity of animals (*Kamme et al., 2003*). In support of this (*Jeppsson, 2000*), names dust and its accompanying microorganisms as the main causes of incident respiratory diseases of animals and breeders. Maintaining clean ambient air in growing areas implies a rational reduction of undesirable impurities in it (*Monteith and Mount, 1973*). Energy intensive, this process involves partial operations: filtration, absorption of undesirable gas components, and dedusting. Filtration of ambient air implies separation of liquid and solid impurities, absorption of local adhesion, i.e. reduction of the concentration of undesirable gas components through adhesive forces, while dedusting is the forced removal of solid particles from the ambient air, e.g. by inertia or centrifugal force (*Zoranović et al., 2007., 2009*). With the aim of reducing ecological, energy and qualitative problems in the field of animal farming, the Laboratory for Agricultural Techniques in Animal Husbandry, Department of Agricultural Techniques, Faculty of Agriculture, University of Novi Sad, integrally develops a system for wet air purification- wet scrubber and its energy control.

The task of electrical measurements in a wet scrubber is to determine current and interval accurate values of selected electrical quantities, defined by physical methods, and embodied by coherent measurement units of the SI system. In general, today's instruments for electrical measurements provide the possibility of insight into the precise values of basic electrical quantities: current strength, electromotive force and voltage, impedance, electrical work, power, and energy.

Simple periodic voltages and currents are crucial for wet scrubber drive elements. While constant DC voltage and current are scalar quantities, represented by an algebraic number, they are periodic voltages and currents determined by three quantities: amplitude, frequency, and phase. Thus, the laws of their calculation and graphical representation are related to the application of various algebraic, trigonometric, exponential and vector functions, (*Tijanić, 1970*).

MATERIAL AND METHOD

According to the basic knowledge in the field of the forms of electrical energy and the natural laws of their sizes, with special reference to the simple periodic alternating form, the basic patterns for the measured sizes of the wet scrubber drive elements are derived:

- operation of simple periodic alternating current,
- power of simple periodic alternating current,
- power of simple periodic alternating current with active resistances in the circuit and
- power of simple periodic + alternating current with impedance in the electric circuit.

Representation of a larger number of drive elements for partial operational operations in the wet scrubber and the protocol-limited descriptive space are the reasons for choosing the central sprayer as the object of the methodologically original energy analysis of this paper. For the comprehensive implementation of demanding electrical, kinematic and dynamic measurements, measuring instruments are provided: a three-phase electrical meter for reactive energy (reactive power factor sinφ), a reference three-phase meter for active electrical energy consumption, a series of local three-phase and single-phase meters, six digital meters for measurement voltage, current, electricity consumption energy and active power factor cosφ, universal current clamp DC/AC, digital multimeter/oscillograph, non-contact-contact tachometer, digital strobe, more diverse unimeters. etc. Data processing in Excel and MathCad.

RESULTS AND DISCUSSION

Simple alternating current operation

Since in a simple alternating current circuit, the voltage and current continuously change, according to a sine or cosine function (phase shift by $\pi/2$), thus its operation, from moment to moment, is different and enables the application of Ohm's law for direct current:

$$dA = e \cdot i \cdot dt \tag{1}$$

where they are: A – work done by alternating current, J; e – voltage, V; i – current, A; t – time, s.

To determine the total work done by the alternating current, in the period of time *t*, it is necessary to integrate an infinite number of elementary works in it:

$$A = \int_0^t e \cdot i \cdot dt \tag{2}$$

Of course, the calculation of the definite integral, according to the known laws of change of current and voltage as a function of time *t*, is simple. In doing so, it is possible to eliminate one of the variables, because *e* and *i* are connected through the active electrical resistance *R* and the total reactance *x*, as adopted constants of the electrical working circuit:

$$A = (R + j \cdot x) \cdot \int_0^t i^2 \cdot dt = \frac{1}{R + j \cdot x} \int_0^t e^2 \cdot dt \tag{3}$$

because $e = (R + j \cdot x) \cdot i$, and $\vec{Z} = \vec{R} + j \cdot \vec{x}$ represents the impedance of the series connection *R*, x_L i x_C.

Here, *x* is the total reactance-resistance, wherein the series connection of the circuit, by their nature, the inductive and capacitive reactances are subtracted from each other:

$$x_L = 2 \cdot \pi \cdot f \cdot L = 2 \cdot \pi \cdot \frac{1}{T} \cdot L = \omega \cdot L \text{ and}$$

$$x_C = \frac{1}{2 \cdot \pi \cdot f \cdot C} = \frac{1}{\omega \cdot C} \quad x = x_L - x_C = \omega \cdot L - \frac{1}{\omega \cdot C} \tag{4}$$

where they are: *j*- imaginary unit, $j = \sqrt{-1}$; *T*- period of current and voltage, *s*; x_L- inductive resistance, *Ω*; *f*- frequency of simple alternating current, *Hz*; *ω*- circular frequency of simple alternating current, s^{-1}; *L*- coil inductance, *H*; *C*- capacitor capacitance, *F* i x_C– capacitive resistance, *Ω*.

Power of simple alternating current

By definition, power is the rate at which work is done:

$$p = \frac{dA}{dt} = e \cdot i \text{ , } \boldsymbol{W} \tag{5}$$

which during an arbitrary period, in a closed circuit, produces the mean power p, as a quotient between the sum of elementary works and the observed time of their execution. Since simple periodic alternating current is current here, its period *T* is chosen for the time period, which means:

$$P = \frac{1}{T} \cdot \int_0^T p \cdot dt = \frac{1}{T} \cdot \int_0^T e \cdot i \cdot dt \text{ , } \boldsymbol{W} \tag{6}$$

Simple alternating current power with active resistances in the circuit

In a closed circuit, with only active resistance *R*, or other resistances being neglected, simple periodic alternating current flows, current values and, as a product of the simultaneous voltage value *e*, without mutual phase displacement, the following relationships apply:

$$\vec{Z} = \vec{R} \text{ , } e = E_m \cdot \sin \omega \cdot t \text{ ,}$$

$$i = I_m \cdot \sin \omega \cdot t = \frac{E_m}{R} \cdot \sin \omega \cdot t \text{ .} \tag{7}$$

Substituting general values from equation (7) into (6) follows:

$$P = \frac{1}{T} \cdot \int_0^T E_m \cdot I_m \cdot \sin^2(\omega \cdot t) \cdot dt = \frac{E_m \cdot I_m}{T} \cdot \int_0^T \sin^2(\omega \cdot t) \cdot dt \tag{8}$$

By introducing the first shift as part of a specific integral:

$$u = \omega \cdot t \rightarrow du = \omega \cdot dt \rightarrow dt = \frac{du}{\omega} \rightarrow \int_0^T \sin^2(\omega \cdot t) \cdot dt =$$

$$\int \sin^2 u \cdot du \cdot \frac{1}{\omega} = \frac{1}{\omega} \int_0^t \sin^2 \cdot u \cdot du$$

From the known trigonometric transformation

$$1 - \cos 2 \cdot u = 2 \cdot \sin^2 u \rightarrow \sin^2 u = \frac{1 - \cos 2 \cdot u}{2}$$ and its change to integral $\frac{1}{\omega} \int_0^t \frac{1 - \cos 2 \cdot u}{2} \cdot du = \frac{1}{2 \cdot u} \cdot (\int_0^T du - \int_0^T 2 \cdot u \cdot du)$

By introducing a second shift

$2\cdot u = t \rightarrow 2\cdot du = dt \rightarrow du = \frac{dt}{2}$, follows:

$$\int_0^T \cos(2\cdot u)\cdot du = \int_0^T \cos t\cdot dt\cdot\frac{1}{2} = \frac{1}{2}\cdot\int_0^T \cos t\cdot dt = \frac{\sin t}{2} = \frac{\sin(2\cdot u)}{2} \rightarrow$$

$$\frac{1}{2\cdot u}\cdot\left(\int_0^T du - \int_0^T 2\cdot u\cdot du\right) =$$

$$\frac{1}{2\cdot\omega}\cdot\int_0^T\left(u - \frac{\sin(2\cdot u)}{2}\right) = \frac{1}{2\cdot\omega}\cdot\int_0^T\left(\omega\cdot t - \frac{\sin(2\cdot\omega\cdot t)}{2}\right) =$$

$$\frac{1}{4\cdot\omega}\int_0^T\left(2\cdot\omega\cdot t - \sin(2\cdot\omega\cdot t)\right).$$

Since $\omega = 2\cdot\pi\cdot f$, by letting go of the limits

$$\int_0^T \sin^2(\omega\cdot t)\cdot dt = \frac{1}{4\cdot\frac{2\cdot\pi}{T}}\cdot\left(2\cdot\frac{2\cdot\pi}{T}\cdot T - \sin\left(2\cdot\frac{2\cdot\pi}{T}\cdot T\right)\right) = \frac{4\cdot\pi\cdot T}{2\cdot 4\cdot\pi} = \frac{T}{2}$$

whereby equation (8) turns into:

$$P = \frac{E_m\cdot I_m}{2} = \frac{R\cdot I_m^{\,2}}{2} = \frac{E_m^2}{2\cdot R} \tag{9}$$

By transforming the expression of equation (9), we get:

$$P = \frac{E_m\cdot I_m}{\sqrt{2}\cdot\sqrt{2}} = E_e\cdot I_e \tag{9a}$$

where E_e and I_e are the effective voltage and current, respectively. By comparing equation (9a) with the equation for direct current power:

$$P = E\cdot I = E\cdot\frac{E}{R} = \frac{E^2}{R} = R\cdot I\cdot I = R\cdot I^2 \tag{9}$$

equation (9a) takes the form:

$$P = \frac{E_m\cdot I_m}{\sqrt{2}\cdot\sqrt{2}} = E_e\cdot I_e = \frac{E_e^{\,2}}{R} = R\cdot I_e^2 \tag{9b}$$

The effective voltage and current are in a constant relationship with the maximum values E_m and I_m, with the character of real physical meaning. Namely, E_e and I_e represent the magnitudes of voltage E and current I, which DC electricity would have to achieve the same average power as AC. Therefore, by applying classical mathematical laws, the effective values E_e and I_e represent the squares of the mean values, defined by the equations:

$$E_e = \sqrt{\frac{1}{T}\cdot\int_0^T e^2\cdot dt} \text{ and } I_e = \sqrt{\frac{1}{T}\cdot\int_0^T i^2\cdot dt} \tag{11}$$

The importance of this analysis is a step forward in simplifying the calculation of the power of simple-periodic alternating current, by replacing the values of its effective voltages and currents into expressions for the relative quantities of direct electric energy.

Simple alternating current power with impedance in the circuit

When representing the impedance of a closed circuit for simple periodic alternating electrical energy, the average engaged power is determined by applying equation (8). Bearing in mind the complex nature of impedance, as a quantity independent of time, the formation of the equation for the engaged power requires the following dependencies:

$$\vec{Z} = \vec{R} + j\cdot\vec{x} = \vec{Z}\cdot(\cos\varphi + j\cdot\sin\varphi)\,; \quad i = I_m\cdot\sin\omega\cdot t$$

$$e = E_m\cdot\sin(\omega\cdot t + \varphi) = \vec{Z}\cdot i \text{ and } Z = \frac{E_m}{I_m}, \tag{12}$$

where φ is the voltage phase shift angle according to the current in radians, as a consequence of the total reactance of the observed circuit.

Substituting the general values of the relative quantities of equations (12) into equation (8) follows:

$$P = \frac{1}{T}\cdot\int_0^T e\cdot i\cdot dt = \frac{1}{T}\cdot\int_0^T \vec{Z}\cdot i^2\cdot dt = \frac{1}{T}\cdot\int_0^T (R + j\cdot x)\cdot I_m^2\cdot\sin^2\omega\cdot t\cdot dt =$$

$$\frac{(R + j\cdot x)\cdot I_m^2}{T}\cdot\int_0^T \sin^2(\omega\cdot t)\cdot dt = \frac{R\cdot I_m^2}{2} + j\cdot\frac{x\cdot I_m^2}{2} = \frac{E_m\cdot I_m}{2}\cdot\frac{R + j\cdot x}{Z} \tag{12a}$$

For known impedance and defined effective values of current and voltage, further transformation results in the equation:

$$P = E_e\cdot I_e\cdot(\cos\varphi + j\cdot\sin\varphi) \tag{13}$$

A logical conclusion follows from this equation: "The power in a closed circuit of simple, periodically alternating electrical energy is a complex quantity, with clearly defined components: active + reactive." Vector and scalar written:

$\vec{P} = \vec{P}_R + j\cdot\vec{P}_x$ i $\vec{P} = \vec{P}\cdot(\cos\varphi + j\cdot\sin\varphi)$,

$P_R = E_e\cdot I_e\cdot\cos\varphi$ - active power;

$P_x = E_e\cdot I_e\cdot\sin\varphi$ - reactive power; (13a)

$P = E_e\cdot I_e$ - apparent power amplitude and

$\vec{P}$ - apparent power vector.

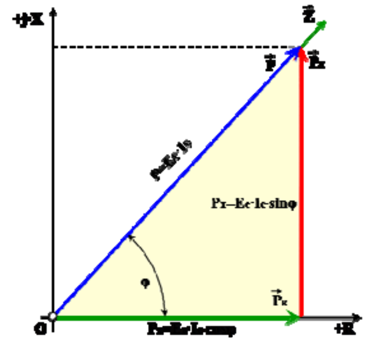

Fig. 1. Apparent power vector components

Apparent power is independent of time, and its vector coincides with the impedance vector, fig.1.

The active power of the electric circuit P_R is part of the apparent power P, due to the active resistance converted into heat, expressed in W. The factor *cosφ* indicates the part of the apparent power converted into active work, which is why it got the name power factor.

The reactive power P_x is the exchanged part of the apparent power with the electrostatic field in the capacitor and the magnetic field of the inductor (winding), during each period of alternating current.

Physically, that part of the power is not irretrievably consumed from the electrical energy source but is communicated to the reactive elements of the working circuit, and then they return it to the circuit in the remaining segment of time. For practical reasons, the unit for this power is the reactive volt-ampere*, VAr*. The factor *sinφ* represents the degree of reactivity of the impeller. At *sinφ=0*, the circuit is purely active.

Average total and effective power of the wet scrubber central rotor

Measurement of the TM's electricity consumption at idle

After removing the two trapezoidal belts, fig. 2, the contactor K3 and the auxiliary axial fan AV are activated in parallel via the microswitch MP for serial air flow around the housing of the three-phase electric motor TM, connected in a star. The activities of K3, and thus of TM, are conditioned by the adjustable degree of heating of the TM housing via the TMS thermostat. This created the conditions for activating the protective circuit breaker SS and through it the inverter INV, with a maximum apparent power output of 7.5 kW. Next follows the measurement of the INV input voltage, with a digital unimeter MU. By setting the start frequency to 5 Hz, INV is activated, with parallel measurement and accompanying tabular record of the following quantities:

- voltage at the input of INV, with MU and multimeter-oscilloscope OSC, (E_{eoR}, E_{eoS}, E_{eoT});
- current on phase lines R-S-T at the input of INV, using current clamps (I_{eoR}, I_{eoS}, I_{eoT}) and
- current I_{eoRI}, I_{eoSI}, I_{eoTI} (average I_{eo}) ; voltage E_{eoRI}, E_{eoSI}, E_{eoTI} (average E_{eo}) and frequency f_{R0I}, f_{S0I}, f_{T0I} (average f_{0I}) on the connection contacts of the TM, via current clamps and OSC;
- use a digital stroboscope and a non-contact mechanical tachometer to measure the RPM of the TM, (n_{M0}) and
- after the expiration of the measurement time of active alternating electrical energy consumption (T=5 min), a tabular record of the values read from the three-phase meters follows: FBRE-reactive energy, reference (summary) TBR and local TB (only for TM).

All the mentioned measurement-recording steps are repeated in sequence, with a threshold of 1Hz, in an interval of 5-50 Hz. This is how the energetic "operational characteristic" of the TM at idle was formed, as a real part of the process of purifying the ambient air with a wet scrubber, and through the central atomizer CR. By reading the value of the consumption of reactive electricity from the TBRE, the value of the power factor $\sin\varphi_0 \rightarrow \varphi_0 = \arcsin\varphi_0 \rightarrow \cos\varphi_0$ is obtained. The average engagement power of the TM, based on the active energy from the ETBO meter, is defined as:

$$P_{eo} = \frac{E_{TBO}}{T}, \text{ kW} \qquad (14)$$

For the calculation of the average engaged power of the TM, in interaction with the accompanying elements of the impeller, all real, inductive and capacitive resistances are included, i.e. impedance, according to the general pattern:

$$P_{eo} = \sqrt{3} \cdot E_{eo} \cdot I_{eo} \cdot \cos\varphi_{oP} \rightarrow \cos\varphi_{oP} = \frac{P_{eo}}{\sqrt{3} \cdot E_{eo} \cdot I_{eo}} \qquad (15)$$

Therefore, the measured and calculated power factors, $\cos\varphi_0$ and $\cos\varphi_{0P}$, respectively, do not belong only to the TM, where its impedance is the result of the sum of the real resistance of three windings, connected in a star, and their reactances in the form of inductive resistance.

Measurement of TM's electricity consumption during CR operation

When driving the CR shaft, without the presence of mesh vanes, with a stepped change in the INV frequency, for naturally functional reasons of a reduced range of 5-20 Hz, taking into account the kinematics and dynamics of the torque transfer from the TM drive pulley to the CR driven pulley -a, the law of change of mean engaged power P_{e1} is determined. The difference between P_{eo} and P_{e1} will result in the average engaged power to drive the CR, without mesh vanes, *Pcro*. Therefore, with the return of the two trapezoidal belts, along with their accompanying tightening by the force Fz, fig.3, due to the potential slippage δ, during the transmission of the torque from the TM to the CR shaft, there will be a loss of power due to the slippage P_δ, i.e. torque reduction M_G. P_δ is a consequence of the friction of the belt on the grooves of the polyethylene pulley of the CR along the inclusive line $(d/2)\cdot\alpha_2$.

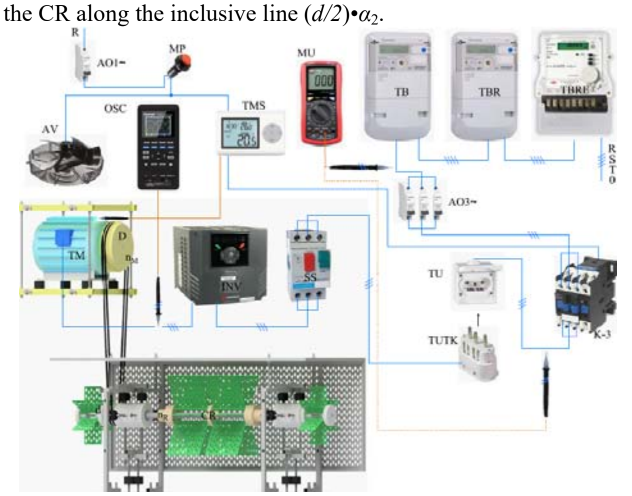

Fig. 2. Scheme of electrical measurements of CR in VFF
R, S, T – phase potential; 0 – zero potential; AO3~– one-piece automatic fuses; MP- power switch; AV- axial fan; OSC – oscilloscope; TMS – thermostat; MU – unimer; TB – three-phase meter, TBR – reference three-phase meter; TBRE – three-phase reactive energy meter TM – three-phase motor; D – pulley diameter on the motor; nM – motor rpm; CR – Central rotor; d – pulley diameter of CR; nR – rpm of CR; INV – inverter; SS – current switch; K-3 – contactor; TU– three-phase socket; TUTK- three-phase plug.

When transmitting torque with a trapezoidal belt, the tension force is approximately greater than the peripheral force of the drive pulley, $F_z \approx 2 \cdot F_P$. At $M_P = M_G \rightarrow \delta = 0$, thus the friction force $F_{tr} = F_z \cdot \mu_o$ (16), i.e. is equal to the product of the normal force and the coefficient of static friction between the abutting surfaces of the belt and the grooves of the CR polyethylene pulley. As soon as the friction force is smaller than the peripheral force F_{P1}, slippage δ occurs on the CR pulley. For a defined transmission ratio of the diameter of the contact surfaces of the driving and driven pulleys, $i = D_s/d_s$ (17), measured engine revolutions, n_M and driven pulleys, n_R, the slip is defined by the equation:

$$\delta = \frac{n_M \cdot i - n_{R\delta}}{n_m \cdot i} \qquad (18)$$

where is $n_{R\delta}$ measured reduced number of revolutions ***CR***-a. With fig. 3 logical relationships are:

$$M_P = F_P \cdot \frac{D_S}{2}; \quad M_G = F_{P1} \cdot \frac{d_S}{2} \text{ and for } \delta=0, \quad M_P = M_G \text{ and}$$

$$P_\delta = 0 \qquad (19)$$

Further arrangement is:

$$F_{P1} = F_P \cdot \frac{D_S}{d_S} \qquad (20)$$

which is an obvious increase in the peripheral force of the CR pulley, and the consequence is the need to install the TM outside the chamber of the wet scrubber, primarily due to its bulkiness (high resistance to air flow) and the conditional conditions of the wet chamber, as well as the anticipated need to multiply its maximum number of revolutions from 2790 to 4000 min^{-1}. With fig. 3 is also noticeable:

$$F_{tr} = \mu_0 \cdot F_Z \rangle F_{P1} \rangle \frac{D_S}{d_S} \cdot F_P \quad (21)$$

At the defined values for D_S and d_S, the determination of the critical force F_{P1K} follows. Based on measurements during CR operation, without net vanes, according to the procedure described in the previous subsection, the following is obtained:

$$P_{e1} = \frac{E_{TB1}}{T} \quad (22)$$

The mean engaged power for the CR drive is calculated according to the already defined equation:

$$P_{CR0} = P_{e1} - P_{eo} \quad (23)$$

By definition it is:

$$P_{CR0} = M_G \cdot \omega_1 = F_{P1} \cdot \frac{d_S \cdot \pi \cdot n_R}{60} \rightarrow F_{P1} = \frac{60 \cdot P_{CR0}}{d_S \cdot \pi \cdot n_R}, N \quad (24)$$

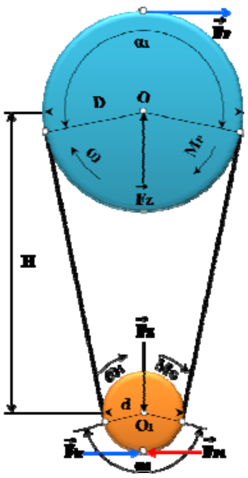

Fig. 3. Torque transmission

However, at the moment of realization of $F_{tr}<F_{P1}$, it will be $\delta>0$, according to pattern (18). According to the logical assumption, mathematically and experimentally confirmed, there is an unequivocal conclusion about belt slippage only by the peripheral angle of the RC pulley, α_2. The peripheral speed of the CR pulley is defined as:

$V_{P1} = \frac{d_S \cdot \pi \cdot n_R}{60}$, $m \cdot s^{-1}$. Pri $\delta>0$ $n_{R1}<n_R$, what is it

$$V_{P1K} = \frac{d_S \cdot \pi \cdot n_{RK}}{60} \quad (25)$$

The belt slip speed is:

$V_\delta = V_{P1} - V_{P1K}$, and loss of power to slippage $P_\delta = V_\delta \cdot F_{tr1}$, at

$$F_{P1K} = \frac{60 \cdot P_{CRK}}{d_s \cdot \pi \cdot n_{RK}}. \quad (26)$$

Slippage of the belt at speed V_δ takes place with the dynamic coefficient of friction μ, which defines the modified friction force:

$F_{tr1} = \mu \cdot F_Z \cong F_{P1K} = \frac{60 \cdot P_{CRK}}{d_S \cdot \pi \cdot n_{RK}} \rightarrow \mu \cong \frac{60 \cdot P_{CRK}}{d_s \cdot \pi \cdot n_{RK} \cdot F_Z}$. At $\delta=0$, from(21) follows:

$$F_{tr} = \mu_0 \cdot F_Z = F_{P1} \rightarrow F_Z \cong \mu_0 \cdot F_{P1} \cong const. \quad (27)$$

Coefficients μ_0 and μ can be experimentally determined based on the original laboratory mechanism, with an accompanying electronic device for measuring and continuous force recording on a constant path, for three basic forms of movement: uniform, uniformly accelerated and variable. The results of this research will be the subject of dedicated analyses, embodied in the public record.

Measurement of the electrical energy consumption of the TM during the operation of the CR with mesh blades

By installing mesh vanes, with the implementation of the measurement steps presented in the previous two subsections, the engaged electrical energy E_{TB2} is read, followed by the average engaged power P_{ML}, with the accompanying structure:

$$P_{e2} = \frac{E_{TB2}}{T} \rightarrow P_{e2} = P_{eo} + P_{CR0} + P_{ML} + P_\delta \rightarrow$$

$$P_{ML} = P_{e2} - (P_{eo} + P_{CR0} + P_\delta), \text{ kW}. \quad (28)$$

The first two sub-chapters present a database for the formation of the energy characteristic of CR at idle speed, represented by a group diagram, with functional dependencies indexed by sub-chapters with Roman numerals I, II and III:

$n_{MI} = f(f,H_Z), P_{eo} = f(f,H_Z), n_{MII} = f(f,H_Z),$

$P_{CR0} = f(f,H_Z), \delta_{II} = f(f,H_Z),$

$P_{CR0\delta} = f(f,H_Z)$, $\delta_{III} = f(f,H_Z)$, $P_{ML} = f(f,H_Z),$

$n_{MIII} = f(f,H_Z)$, $P_{ML\delta} = f(f,H_Z),$

where are:

$P_{CR0\delta} = f(f,H_Z) = P_{CR0} - P_\delta$ - average power engaged to drive the CR at idle with potential belt slip on its polyethylene pulley grooves,

$P_{ML\delta} = f(f,H_Z)$- average engaged power to drive CR with mesh blades, at adequate δ.

All the listed quantities with index III are obtained by processing the data from the third subchapter

CONCLUSION

For the sake of a clearly framed presentation, in the paper the forms for the measured electrical, kinematic and dynamic quantities of the driving electric motor of the CR and accompanying transmission elements in the wet scrubber were derived. Within that, the electrical quantities described are:

- operation of simple periodic alternating current,
- power of simple periodic alternating current,
- power of simple periodic alternating current with active resistances in the circuit and
- power of simple periodic alternating current with impedance in the electric circuit.

Adequate measuring instruments are provided for the comprehensive realization of numerous electrical, kinematic and dynamic measurements. According to the logical assumption, mathematically and experimentally confirmed, there is an unequivocal conclusion about belt slippage only by the peripheral angle of the RC pulley, α_2. Coefficients μ_0 and μ can be experimentally determined based on the original laboratory mechanism, with an accompanying electronic device for measuring and continuous force recording on a constant path, for three basic forms of movement: uniform, uniformly accelerated and variable. The results of this research will be the subject of dedicated analyses, embodied in the public record.

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