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Analysis of power demand signal in laboratory rotary mixer

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Abstract

The paper summarises the power measurement data for the main assemblies in a prototype turbine mixers for laboratory applications. Of particular interest are power demand signals in the paddle stirrer and the rotor. Tests were performed for the variable moisture content of the moulding sand containing bentonite. The process is described as dynamic and considered from the standpoint of automatics. Potential applications of the power demand signal are investigated in the context of the study of dynamics of the mixing processes, in terms of control of the water feeding to the moulding sand and for the purpose of evaluating the energy consumption.

Keywords: Foundry Processes, Preparing of Moulding Sand, Power Measurements of Mixers Drive

1. Introduction

Most systems used in control of sand preparation processes are based on the relationships between sand parameters and its moisture content. Moisture measurements are taken with various types of sensors placed inside the mixer or also at selected points of the sand preparation line [2, 9, 10]. Furthermore, there are automatic systems for measuring the sand's technological parameters used for online monitoring of the sand being prepared and for process control (online updating of the amounts of ingredients to be fed). An example here is the Multicontroller system SMC-PRO, manufactured by the DISA Group [9]. Applications of the measurement signals of the mixer drive's power components to the assessment of the sand condition and to the control of sand preparation processes were explored in previous publications by the authors [5, 6], which present the newly-designed original microprocessor system for implementation of such measurements. Power measurements of the mixer's drive are given below, tests were run on a turbine mixer based on a paddle mixer MS75 (from Dozamet Nowa Sól [8]), used in laboratory applications. The test rig is intended for testing the system for measurements of power components. Test results can be further utilised to identify all processes involved in sand mixing.

2. Measurement of selected parameters of power demand of laboratory mixer electric drives

The tested mixer was engineered by providing a paddle mixer MS 75 with a rotor and drive and with a water feeding system. The design of the rotor's drive allows for varying the inclination angle of the rotor axis. Furthermore, the rotor can be replaced by that having a different shape. In terms of functional features, this mixer is an equivalent of the turbine mixer WM, manufactured by Kunkel Wagner [10]. Variations of the rpm speed of the paddle stirrer's drive and of the rotor are made possible by the use of frequency converters. The diagram of the measurement and control system is shown in Fig. 1.

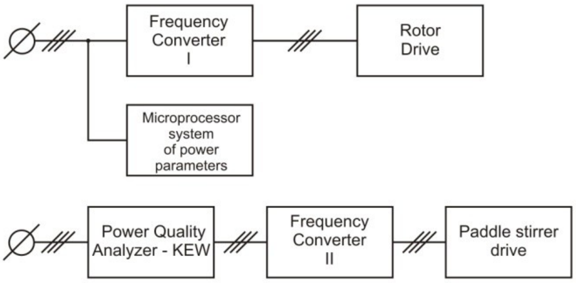


Fig. 1. General block diagram of control and measuring system of laboratory mixer drives parameters

At the early stage of the test procedure, the characteristics are explored between the rpm speed of the rotor and stirrer in the function duly preset on the frequency converter. Measurements were taken with an optical speed meter Testo 460. Selected results are shown in Fig. 2. It appears that the degree of the mixer's charging has little bearing on the rpm speed of the mixer in steady - state conditions.

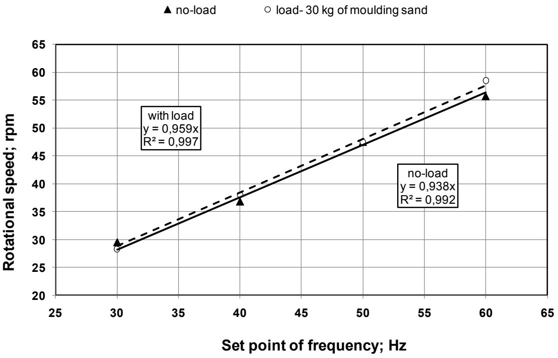


Fig. 2. Rotational speed of paddle stirrer drive versus set point of frequency

The prototype microprocessor system enables the recording of several parameters associated with power demand. The dedicated software allows for graphic representation of registered data and for data transfer to other programs or spreadsheets (Excel).

For comparison, the measurement procedure uses also the power quality analyser KEW 6310, manufactured by Kyoritsu [11], enabling the simultaneous recording of selected power demand parameters of the drives in the rotor and paddle stirrer.

The purpose of this testing program was to evaluate how the variations of sand parameters associated with moisture content should affect the power demand by the mixer's drive throughout its duty cycle.

Synthetic sand used during the tests contained bentonite (silica sand – 100 parts by weight, bentonite – 8 parts by weight). Fig. 3 shows the plots of sand properties. As regards the registered signal of variation of instantaneous power (an active components), the instantaneous values tend to oscillate round the mean value in a lesser degree during the early stages of mixing in relation to the final stage (Figs 4, 5).

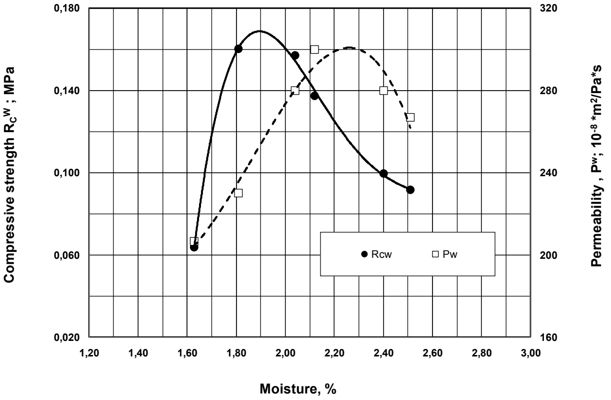
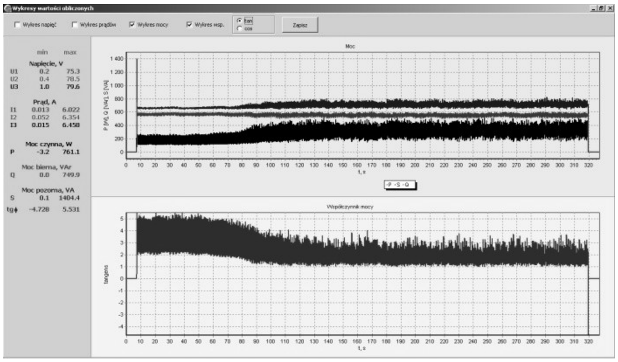


Fig. 3. Basic parameters of moulding sand (each points represent mean value for series of measurements)



	min	max
Napięcie, V		
U1	0.2	75.3
U2	0.4	78.5
U3	1.0	79.6
Prąd, A		
I1	0.013	6.022
I2	0.052	6.354
I3	0.015	6.458
Moc czynna, W		
P	-3.2	761.1
Moc bierna, VAr		
Q	0.0	749.9
Moc pozorna, VA		
S	0.1	1404.4
tgφ	-4.728	5.531

Fig. 4. Exemplary view of window in a program of recording of selected power parameters values during mixing period

When interpreting the plots, variations of rheological properties and associated technological parameters (moisture content) of moulding sand are of particular importance [1, 2, 7]. The apparent density of moulding sand changes considerably from low moisture content (of the order or 1%) to about 2%. It is well apparent (see Fig. 3) that the moisture content of the tested sand mix is associated with the compression strength R_c^w nearing the maximal value.

Variations of apparent density of the moulding sand during the mixing process had an effect on position of its free surface and hence the level of rotor's immersion in the moulding sand. In the consequence, the registered power signals changed, too. A thorough analysis reveals periodic changes of power consumption in the system, associated with cyclic displacements of the paddle stirrer underneath the rotor. Each passage of one of its two arms causes the local elevation of the sand level, so the rotor was immersed more deeply, leading to increased mixing resistance.

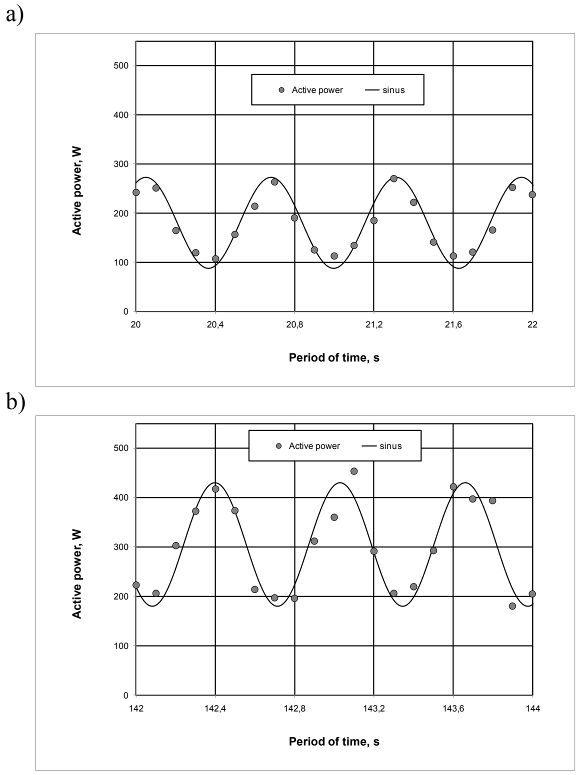


Fig. 5. Changes of active power demand of the mixer rotor at different stages of the mixing process; a) towards the end of water dosing, b) stabilization of average value of the power signal

The window in Fig. 4 shows data registered during the power measurements of the mixer's rotor.

Pulsating power signals correspond to the frequency associated with the stirrer's arm passing under the rotor, related to the rpm speed of the stirrer.

A sine function with frequency associated with the rpm speed of a two-armed stirrer is superimposed on the selected time sections in the plot of the power signal. Selected time sections correspond to the period of mixing sand with low moisture content – power pulsation is decidedly smaller (Fig. 5a), and after moistening in the final stage of the mixing cycle (Fig. 5b). Enhanced power pulsation at that time might be attributable to cyclic, intensive motion of moistened sand in the radial direction (towards the mixer's axis). This kind of sand circulation is associated with the presence of vertical flat bars on the pan's side surfaces in the paddle mixer MS 75. Intensity of motion is closely associated with the moisture content of the moulding sand. Frequency of power signal pulsation throughout the entire measurement cycle changes very slightly whilst major variations of amplitudes of power pulses are revealed during the final stage, as explained above (Fig. 5).

In order to better capture the trends in variations of active power consumed by the rotor drive due to impulsive water dosing, the effective parameters of the signal were computed (by the trapezoids method) during the time periods associated with the obtained frequency of signal pulsation. Results are shown in Fig. 6. Measurement and computation data collected within the first 10 seconds after switching the mixer's drive are neglected, assuming it to be the start-up period. Besides, Fig 6 shows an approximated flow rate of water dosed into the system (in the shape of a rectangular impulse).

When the process is treated as dynamic, it can be described in the simplest terms by a SISO (Single Input-Single Output) model. Taking into account the object's response to the present excitation, the transmittance function governing the model can be given as:

$$G(s) = \frac{Y(s)}{X(s)} = \frac{k \cdot e^{-\tau \cdot s}}{s \cdot (T_1 \cdot s + 1)(T_2 \cdot s + 1)} \quad (1)$$

The model of the process is proposed in the form of the series connection of the integrating element and II order inertial element with time delay (model II in Fig 6). The exciting signal x(τ) is the flow rate of the flux of dosed water, and the response y(τ) is the increment of the effective active power of the rotor's drive.

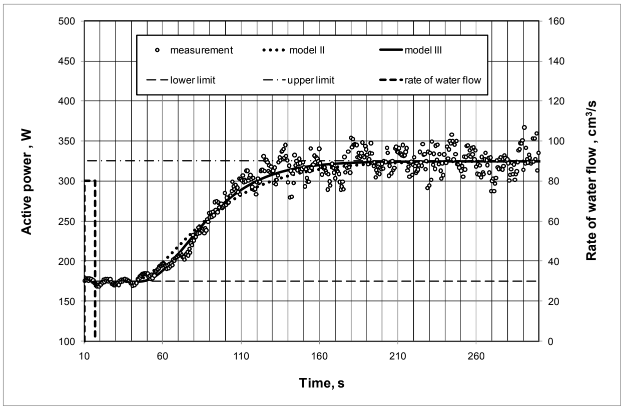


Fig. 6. Active power signal response of rotor drive for impulse input signal – rate of water flow in mixing process

Alternatively, the transmittance function can be given as:

$$G(s) = \frac{Y(s)}{X(s)} = \frac{k \cdot e^{-\tau \cdot s}}{s \cdot (T \cdot s + 1)^n} \quad (2)$$

In this case the process is modelled by the serial connection of an integrating element and n inertial elements of the I order and the delaying element (model III in Fig. 6).

The response patterns were obtained for both transmittance functions by the following methods:

- graphical method for the model governed by Eq. (1)
- graphical – analytical method developed by V. Strejc, for the model governed by Eq. (2)

The time delay readily apparent in Figs 6 and 7 might be attributable to the operation of the water dosing system and intensity of the mixing process (delay in transport). In the presented series measurements the value of τ falls in the interval between 30 and 40 (Fig. 6). Inertial terms present in the transmittance function are associated with the reaction of the binding agent to moisture, with parameters of the mixing process and constructional parameters of the mixer and its drive (for instance time constants in the transmittance of the motor).

In the case of Eq. (1) and (2), impulse excitations lasting for a comparatively short time in relation to the whole process can be treated as a product of ideal excitation signal (Dirac impulse) and a constant, when such signal passes through the integrating element, a step signal is obtained at the output. The form of the final response after the signal's passing through further transmittance components is typical of inertial object of the higher order. In Fig. 6 time response lines are indicated for the two models described above, determined by widely employed methods of the theory of control [3, 4]. A slightly better agreement between the experimental and predicted data is achieved when the second method is employed as the transmittance involves an inertial object of the III order (treated as a serial connection of three identical inertial elements of the I order).

The value of n is obtained n = 3, model III- continuous line on the plot in Fig. 6.

It has to be emphasised that knowing the equation of static characteristic:

$$\Delta \quad = f(\Delta \quad) \tag{3}$$

where:

ΔP – increment of the drive's effective power,

ΔV – the amount of water fed to the given quantity of water (mass),

as well as the time response equation, we can easily control the water dosing process basing on power signal measurements.

Due to disturbances in industrial processes of sand preparation (deviations of the sand temperature) and the fact that other ingredients are fed as well, the model of the mixing process has to be more complex [1, 5].

Effective solution to such an intricate problem requires an excellent identification of all processes involved in sand preparation in turbine mixers.

A similar plot of the power signal is obtained for the paddle stirrer's drive. In this case the measurement are taken with the KEW 6310 analyser while water is dosed in an impulse manner. Measurements of the active power signals are registered with the sampling time 2 s. The increase the pulsation of the active power signal (Fig. 7) with the increase in moisture content is explained above.

3. Summing up

The methodology of measurements of power consumption by the mixer's drive is outlined. In the light of treatment and interpretation of measurement data, further work is merited to develop the system to effectively monitor the power consumption in control of sand preparation processes. Test results reveal major variations in the mixer's drive's loading in the consequence of water feeding. Variations of power demand during the mixing process due to changes in sand parameters are considerable. At that stage further research works are underway, involving the application of more advanced identification algorithms and development of the dedicated software to enable the analysis of a vast body of measurement data obtained even from a single measurement. The form of thus obtained time responses confirms that the time of the mixer's duty cycle can be controlled basing on measurements of parameters of power uptake by the mixer's drive. Such measurements enable the evaluation of the mixer's performance in the context of energy efficiency.

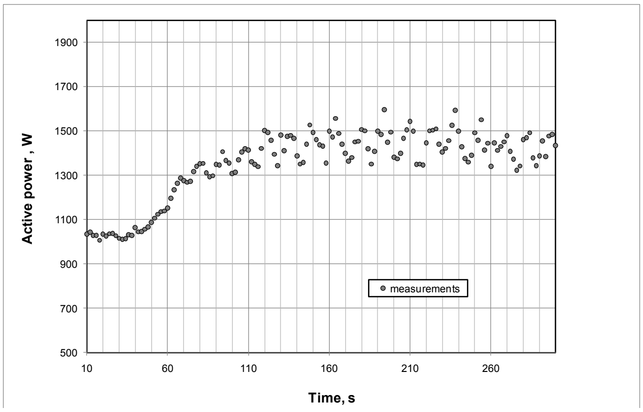


Fig. 7. Active power signal response of paddle stirrer drive for impulse input signal – rate of water flow in mixing process; measurement with KEW analyser

It is reasonable to apply this measurement methodology to optimisation of turbine mixers' design and selection of their operating parameters.

Acknowledgments

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