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PERFORMANCE EVALUATION OF ROTARY MIXERS THROUGH MONITORING OF POWER ENERGY PARAMETERS

OCENA DZIAŁANIA MIESZAREK WIRNIKOWYCH POPRZEZ MONITOROWANIE PARAMETRÓW ENERGETYCZNYCH

A method is outlined that can be adopted for measuring the power demand by moulding sand mixers using a dedicated computer system enabling the monitoring and recording of instantaneous voltage and current levels of power taken up by foundry machines and installations. This system allows the operational parameters of electric-powered devices to be effectively monitored. Of particular importance is the energy efficiency level. Monitoring of the machine operation is also required for evaluation of the sand preparation processes. The methodology of measurements and processing of measurement data is explained using the example of a state-of-the-art rotary mixer for laboratory applications. Tests have confirmed the adequacy and good performance of the microprocessor system used in measurements, allowing the energy efficiency parameters of the mixer drive to be determined. The fundamental aspects involved in power demand monitoring include: optimisation and control of the mixing process, taking into account the sand quality and mixer performance. It has to be emphasised that the measurement results can be also utilised in optimisation of the machine's constructional and operational features. Tests confirm that variations of moisture content in sand can impact on selected power energy parameters.
Keywords: foundry engineering, foundry machines, moulding sand mixers

W artykule przedstawiono metodykę pomiarów poboru mocy przez mieszarki masy formierskiej, z zastosowaniem oryginalnego komputerowego systemu przeznaczonego do monitorowania i rejestracji chwilowych wartości napięć, prądów i mocy pobieranej przez odlewnicze maszyny i urządzenia. System ten umożliwia kontrolę eksploatacyjnych parametrów urządzeń o napędzie elektrycznym. Istotnym parametrem jest energochłonność. Poprzez monitorowanie pracy urządzeń, możliwa jest również ocena procesu technologicznego sporządzania masy formierskiej. Metodykę pomiarów oraz sposób analizy wybranych wyników omówiono na przykładzie badań nowoczesnej, wirnikowej mieszarki laboratoryjnej. Przeprowadzone badania potwierdziły funkcjonalność i przydatność zastosowanego w pomiarach mikroprocesorowego systemu. Umożliwia on określenie szeregu istotnych parametrów z punktu widzenia energochłonności pracy napędów mieszarki. Podstawowe, istotne aspekty monitoringu poboru mocy to: optymalizacja i kontrola procesu mieszania, uwzględniająca jakość sporządzanej masy formierskiej oraz ocenę poprawności pracy mieszarki. Podkreślenia wymaga również możliwość wykorzystania wyników pomiarów w optymalizacji konstrukcji i eksploatacji urządzenia. W badaniach potwierdzono wpływ zmiany wilgotności masy na wybrane parametry energetyczne.

1. Introduction

Monitoring plays a major role in supervision and status identification of machine operation [1,2,3]. From the standpoint of methodology, it appears that the research program should encompass the entire process, involving the preparation for machine operation and its evaluation. Of particular importance is the operational stage, whereby the machines are used for the purpose for which they are intended. Evaluation of the machine operation involves the performance testing of machines and installations, resulting in qualitative and quantitative changes, or the changes of physico-chemical properties of materials [2] using in the manufacturing of castings.

The classical example of transforming the properties of materials are sand preparation processes in mixers. No matter what the mixer design, the key element of its structure is a electric drive integrated with the actuator mechanism [4-9]. In the case of mixers that is a mixing mechanism, subjected to variable loads. The applied load controls the sand properties, which can be captured quantitatively through measurements of instantaneous values of voltage, current levels and power uptake by the drive mechanism. The evaluation procedure gives the result expressing the level of energy-efficiency.

In each method of measurements, the accuracy of results is associated with the quality of metering devices. The method outlined in this study uses the dedicated computer-assisted system adopted to the testing of foundry machines and installations. The system incorporates frequency and current transformers (in each of the three phases) and the signals from these devices pass to a microprocessor-based system which processes and transmits the instantaneous voltage and current

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values, via a USB port, to the recording computer. A detailed description of the system is presented elsewhere [1,4,10].

2. Test procedure

Testing was done using a laboratory turbine mixer, which captures the features of new-generation mixers installed in mechanised and automated foundry plants [11,12]. The key mechanisms in the mixer structure are two independent drives: the pan and rotor drives. The mixing effect is achieved through elementary processes acting on the moulding sand during the rotation of the pan and of the rotor [2,11].

The drives are power-supplied via inverters, enabling the control of the rpm speed which determines the physical and chemical properties of moulding sand and the required admixtures in the function of the mixing time. The operating parameters of the inverter are controlled by the microprocessor controller.

The novel feature of the microprocessor-based monitoring system is that power measurements of the drives and the control systems can be taken between the supply mains (or frequency converter) and the mixer device (Fig. 1).

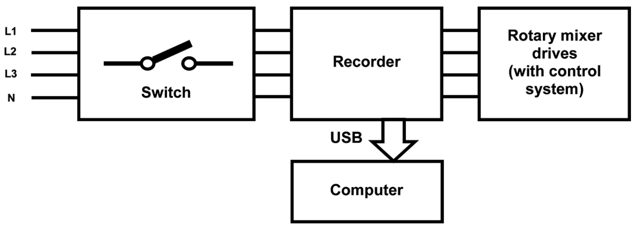

Fig. 1. Schematic diagram of the parameters of power demand by a laboratory turbine mixer

Parameters to be measured include instantaneous values of the relevant signals in periodic patterns of specific shapes, depending on type of the implemented drive control devices. Dedicated software supports the calculations of the basic power indicators, such as the active power taken up by the drive in a machine.

Selected plots of instantaneous parameters pertinent to the turbine-rotor motor operation are shown in Fig 2.

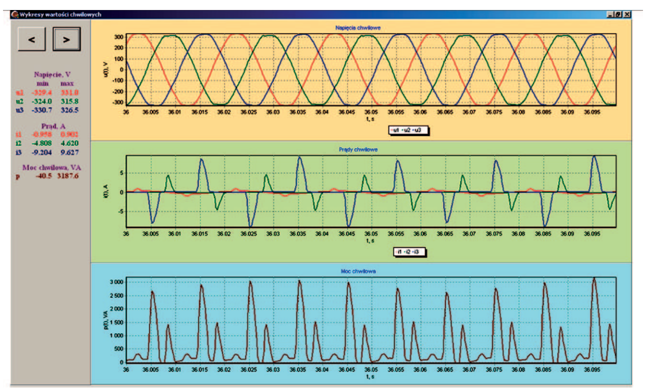

Fig. 2. Window displaying selected patterns of instantaneous voltage, current and power uptake by a turbine mixer

In the measurement system the rms values are obtained basing on instantaneous voltage and current values registered in specified time intervals. Of particular importance is the selection of the sampling time, in which the relevant rms values are to be computed. As most electric parameters are fast-changing, the requirements as to the rate of data recording in the microprocessor system are very high. A large number of signals to be registered requires considerable memory storage capacity and sufficiently fast digital signal processing (DSP) algorithms [1,4,13,14].

3. Analysis and evaluation of measurement data

The methodology of testing the operational status of machines and devices requires the tests in the idle run and under the loading conditions, depending on the implemented process technology. In the case of the investigated rotary mixer, it is not filled with the sand mix during the idle run of the mixer. The DSP algorithm is applied to derive the rms value of power taken up by the control and drive systems, basing on the measured instantaneous current and voltage values under the idle run conditions.

During the measurement procedure the rotating speed of the pan drive was varied while the rpm speed of the rotor drive remained on the predetermined level. Calculated variations of power levels are shown graphically in Fig. 3.

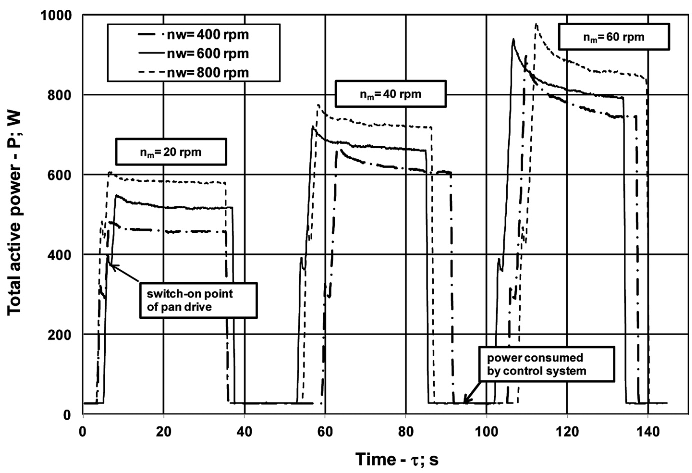

Fig. 3. Total value of active power taken up by the rotary mixer in the idle run

The rationale behind the testing done in the idle run is that the duty cycle of mixers involves several stages: idle run prior to pan filling, operation under loading and between the pan is emptied and recharged. Although the power uptake plots represent the total active power taken up by the mixer drive, it is still possible to identify the values of power taken up by the control system and the approximated levels of power consumed by the rotor and pan drives. During the test series, transients states occurred at the instant of the drive start-up, which was signaled by increased power intake.

Representative values are characteristic of steady-state conditions, the power intake being fully stabilised. Plots of power intake variations under those conditions and in the function of the rpm speed of the pan drive are shown in Fig. 4.

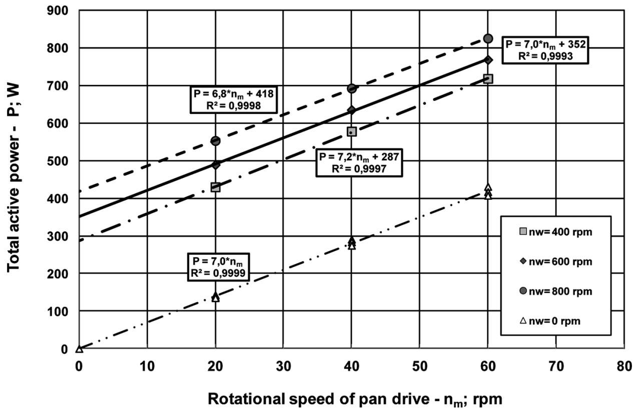

Fig. 4. Active power P intake by the mixer drives under steady – state conditions in the function of the variable rpm of the pan drive n_m

The presented functions are linear, which results from the applied statistical data handling procedure giving the standards deviation for the mean values (about 1%) and the high value of the determination coefficient R^2. The plot in Fig. 4 is supplemented by the trend line (continuous line) for the calculated power uptake values by the pan drive at the 'zero' rpm speed of the turbine.

Fig. 5 summarises the plots of measurement and calculation data, expressing the drive power in the function of the rotating speed of the turbine drive. In this case the trend line is different because the set of measurement data includes the values of power uptake by the pan drive at the 'zero' rpm speed of the turbine. One has to bear in mind, however, that some of the polynomial expressions are empirical only, on account of the large value of the coefficient R^2.

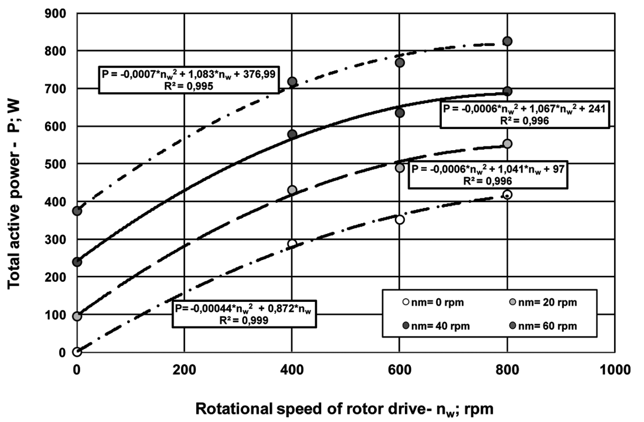

Fig. 5. Active power P intake by the mixer drives under steady –state conditions in the function of the variable rpm of the rotor drive n_w

In practical applications, to evaluate the mixer performance and its energy-efficiency features, it is recommended that the measurement results should be converted into relevant dimensionless indicators (Fig. 6).

The indicators (dimensionless coordinates) are defined as the ratio of turbine drive to the pan drive power $W_p = P_w/P_m$ and a specially determined rotational velocity factor W_n (equation on Fig. 6). Fig. 6 and pertinent equations can be used to find the power uptake during the idle run for the arbitrarily set and variable drive rpm. In place of the trend line (indicated as continuous line) an approximate relationship can be applied: $W_p = W_n$ (broken line). The error involved in the calculation procedure does not exceed 3%.

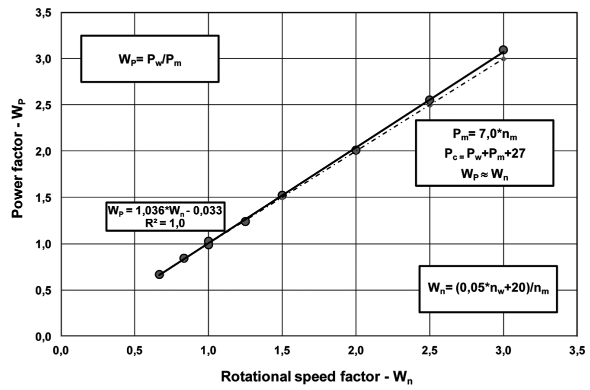

Fig. 6. Power uptake by the rotor and pan drives W_p versus the drive rpm factor W_n (tests include the idle run of the mixer- dimensionless coordinates)

In the next stage of the testing programme, measurements were taken of power uptake during the mixer's duty cycle, the mixer being filled with moulding sand with the specified moisture content. A selected plot of power uptake in the function of time is shown in Fig. 7.

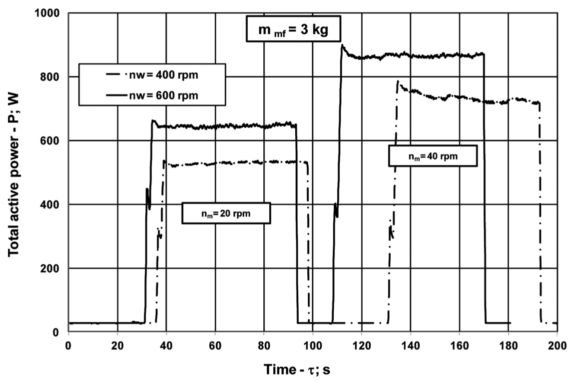

Fig. 7. Total active power taken by a turbine mixer- duty cycle under load, the pan load: 3 kg of moulding sand

Power uptake is the function of loading (the degree of pan filling) and the pan's rpm, these relationships for the steady-state conditions are given in Fig. 8.

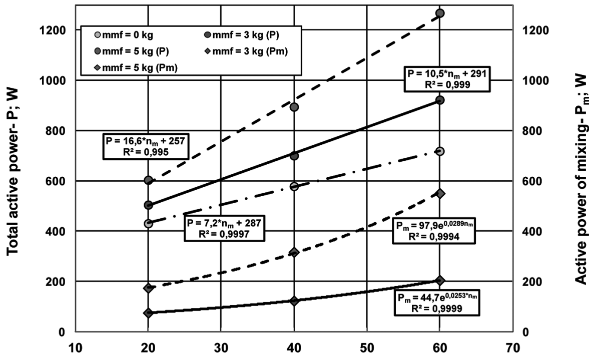

Fig. 8. Active power uptake by the mixer drives under the steady-state operational conditions in the function of a variable pan drive's rpm speed nm during the duty cycle: pan load: 3 and 5 kg of sand, rotor's rotational speed: n_w = 400 rpm.

Curves representing the mixing power are to be interpreted using the exponential type trend lines, which more closely capture the relationship between the power uptake and the pan's rpm.

The research programme was completed by taking measurements of power uptake in the function of moisture content in the sand, which was altered by adding water. A plot of active power demand in the function of the amount of water is shown in Fig. 9.

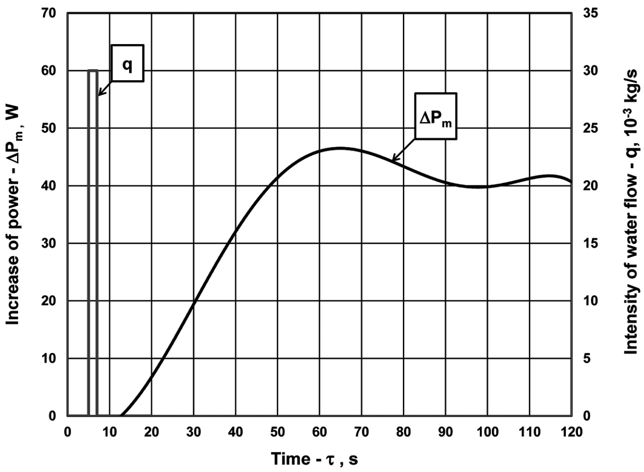

Fig. 9. Time run of increase of active power connected with moulding sand mixing and simultaneous water dosing; load of the pan: 3 kg of moulding sand, change of moisture value ΔW= 2%. (n_w = 600 rpm, n_m = 40 rpm, run of power signal – trendline for mean values, intensity of water flow – approximated by rectangular pulse)

The response of the active power increase signal to a rectangular excitation (approximating the flow rate of the water added) is shown as trend lines obtained for averaged values. Signal corresponds to the nature of the such changes realized in earlier measurements [1,4].

4. Summing-up

Analysis of measurement results suggest that the proposed procedure and instrumentation seems an effective tool to be used in monitoring of electric-powered foundry machines. Measurements and analysis of variability range of selected power energy parameters (voltage, active or apparent power consumption, voltage fluctuations or distortions of the voltage or current patterns in the selected phase of the supply system) offer us a good insight into phenomena taking place during the mixing process. A major advantage of the use of a prototype measurements system (categorised as a new-generation device) is the control of power energy parameters on supply leads. It can be connected at several points of the power-supply system, for example ahead and behind the frequency converter. Measurements of instantaneous values of parameters enable a more reliable analysis of complex phenomena occurring during the moulding sand preparation in rotary mixers. The obtained results have characterised also the rotary mixers in the aspects of energy consumption. Further research should be undertaken to establish the influence of the water addition during the sand preparation process. The methodology should be supported by computer-assisted methods based on numerical algorithms and to be used in analysis of registered electric signals.

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