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Compensation of reactive power in the power-supplying system in a roller mixer in laboratory conditions

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Abstract

Of particular importance are instantaneous voltage and current levels registered in the three-phase power-supplying systems in roller mixer in laboratory conditions. Recorded data allow the apparent power, active and reactive power to be determined as well as power factors cosφ and tgφ for the predetermined parameters of the system sand being mixed and for the given roller sets. On the basis of the registered power fluctuations, the capacity of batteries and condensers compensating the reactive power for the mixer are found. Conclusions are drawn as to technical and economic aspects of the applied compensation strategy.

Keywords: Power consumption, Compensation of reactive power, Roller mixers for foundry engineering

1. Introduction

The analysis of power demand by mixers used in foundry engineering aims to determine the impacts of major parameters of the sand mixing process on the selected parameters of the power-supplying systems: active and reactive power, apparent power and the associated power factor. Parameters involved in system sand preparation include: the pan filling, mixing time, moisture, compression strength and others. These relationships are of key importance when designing control systems to support the sand mixing operations and to minimise the consumption of electric power by the mixers.

The paper summarises the power consumption data of roller mixer in laboratory conditions. Instantaneous voltage and current levels are registered by a specialised recording device, whose detailed functional and technical description is given elsewhere [3, 4]. This measurement technique is more advantageous than methods used by other authors [2].

Conclusions drawn from the analysis of power consumption by the roller mixer were utilised to design and fabricate a compensated reactive power-supply system, which significantly changed the operational parameters and cost-effectiveness of the investigated mixer.

2. Experimental setup

The Simpson type roller mixer (Fig. 1) is equipped with a three-phase 1kW motor, power-supplied directly from the mains.

Power levels are recorded by the microprocessor system fabricated specially for the purpose of the research program and intended for measurements of instantaneous voltage and current levels in three-phase power-supplying systems in electric machines and equipment. Recorded data are fed via a USB port to a computer to store, process and graphically display the results.

The detailed functional and technical description of the microprocessor recorder of instantaneous voltage and current levels is shown elsewhere [3, 4].

The functional diagram of the system for measuring power demand by a laboratory roller mixer is shown in Fig. 2.

Algorithms for computing particular power components and power factors are given elsewhere [3, 4, 5].

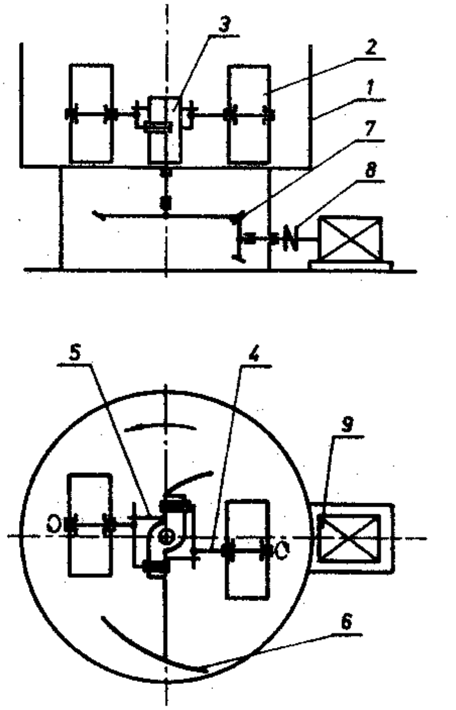


Fig. 1. Simpson type roller mixer [1]: 1- mixer pan, 2- rollers, 3- head, 4- roller axes fixed on balance levers, 5- supports to fix the suspension height

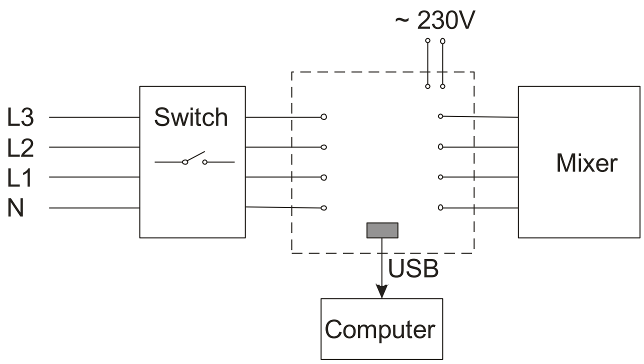
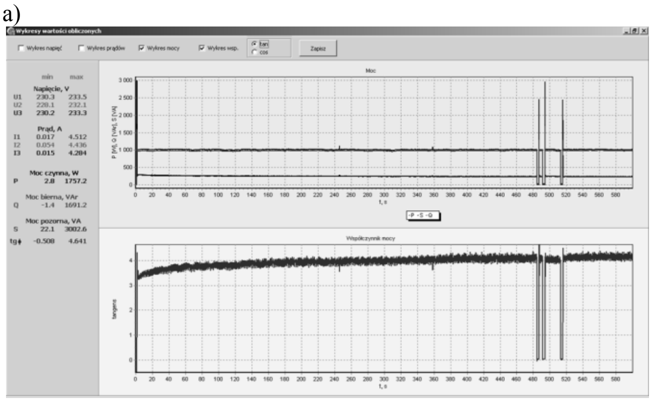


Fig. 2. Computer system for recording power consumption by a roller mixer

3. Measurement and calculation data

Rollers fitted in roller mixers may vary in width. Tests were run on rollers 80mm in width (weight of each roller 14kg) or 120mm in width (21kg). Fig. 3 shows the parts of the windows for archiving and visualisation of computation data derived for an empty roller mixer, the roller width being 80mm and 120mm.

a)



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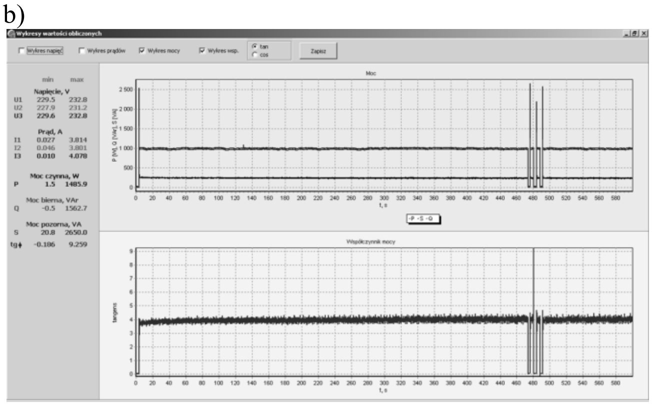


Fig. 3. Windows showing calculated power components and the factor tgφ for an empty roller mixer: a- roller width 80mm; b- roller width 120mm

Plots of particular power components shown in Fig. 3 reveal that apparent power in the steady state approaches 1 kVA, active power consumed by the mixer reaches 280W whilst the factor tgφ assumes the value 4.0, which corresponds to cosφ=0.24. Of major importance is the fact that fluctuations of power components in the function of roller width are rather minor.

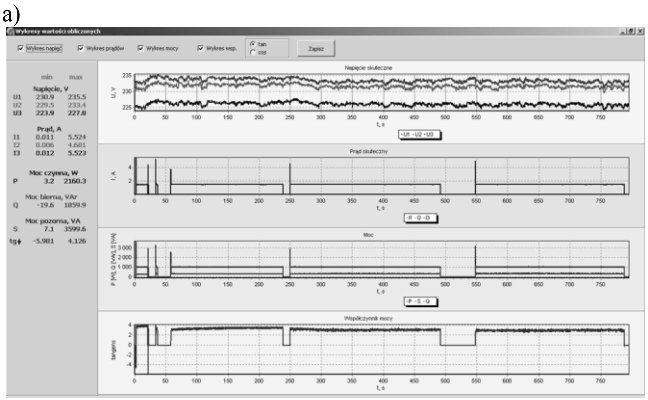
Instantaneous voltage and current levels were first recorded for an empty mixer with the roller width 80 and 120mm, in the subsequent stages the roller mixer was filled with sand mix in the amount of 5kg. The mix contained 4600g of sand, 400g of bentonite and 150ml of water. Registered results and calculation data are summarised in Fig. 4.

The analysis of calculation data in graphic form reveals that the value of the power factor tgφ falls in the interval from 3.0 (for rollers 120mm) to 3.5 (rollers 80mm), which corresponds to the cosφ ranging from 0.27 to 0.32.

This conclusion is of primary importance from the standpoint of engineering and design. Minor fluctuations of power factors do not allow reliable measurements of instantaneous voltage and current levels required for effective control of the sand mixing processes in laboratory mixers.

The range of cosφ fluctuations significantly differs from that allowable by electric power suppliers. In practice, the admissible value ranges from 0.93 to 1.0, which corresponds to the tgφ fluctuations from 0.0 to 0.4.

a)



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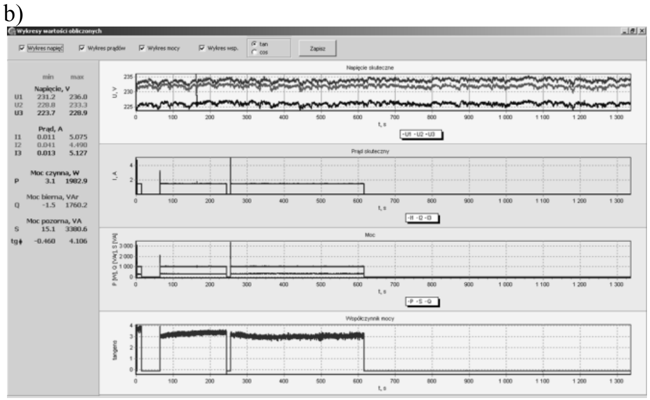

Fig. 4. Window displaying the calculated effective voltage and current levels, power components and tgφ during the mixing of 5 kg of sand (a –rollers 80mm, b-rollers 120mm)

In accordance with the principles of electric power pricing, specified by electric power suppliers, when the value of tgφ exceeds 0.4, an extra rate is charged for excessive absorption of reactive power. For example, the price schedule given in section 4.4.6 [6] defines the extra rates for excessive power demand, in accordance with the formula:

$$O_b = k \cdot C_{rk} \cdot \left(\sqrt{\frac{1 + tg^2\varphi}{1 + tg^2\varphi_0}} - 1 \right) \cdot A \qquad (1)$$

where:

- O_b - rate to be paid for reactive power consumption in excess of the level defined by the power factor tgφ [PLN],
- k - multiplicity of electricity rates, specified for consumers of electric power consumers from low-voltage mains (2.75 in 2009 and 3.0 in 2010),
- C_{rk} - electricity price, PLN/kWh,
- $tg\varphi_0$ - arbitrarily defined power factor, typically approaching 0,4,
- $tg\varphi$ - power factor associated with the consumed reactive power,
- A - active power consumed per day or for the time zone in which the monitoring of reactive power demand is put in place, kWh.

Let w_k stands for the cost index, defined as:

$$w_k = k \cdot \left(\sqrt{\frac{1 + tg^2\varphi}{1 + tg^2\varphi_0}} - 1 \right) \qquad (2)$$

Accordingly, formula (1) can be rewritten as:

$$O_b = w_k \cdot C_{rk} \cdot A \qquad (3)$$

Fig. 5 shows the cost index wk in the function of power factor tgφ, assuming the value in excess of 0.4.

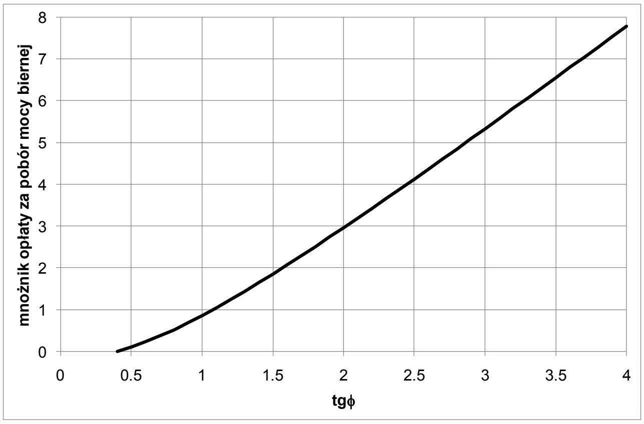

Fig 5. Cost index wk versus tgφ

It is readily apparent (see Fig. 5) that the cost index is roughly equal to 5.3 for tgφ = 3.0 and 6.6 for tgφ=3.5. For example, if the investigated roller mixer absorbs 300 W of active power and 1 kVA of total power (cosφ=0.3 and tgφ=3.18), the cost index becomes w_k = 5.76. Assuming that the mixer is operated in the laboratory for 5 hours daily and for 20 working days, the monthly active power consumption amounts to 30kWh. If the mixer were properly compensated, then in accordance with [6], the variable rate would be charged specified in the price plan C21 for Kraków (after 1 March 2009):

Price= 30 kWh • 0.1287 PLN/ kWh = 3.86 PLN

According to [1], the price charged for excessive demand of reactive power becomes:

$$O_b = 5{,}76 \cdot 30\ kWh \cdot 0{,}1287\ PLN/kWh = 22{,}24\ PLN$$

Hence, the total monthly cost of an uncompensated roller mixer is equal to: 3.86+22.24= 26.10, instead of 3.86. When computing the real costs of mixer operation, we have to consider the constant component specified in the price plan, the quality-related price reduction and the transition charge.

3. Compensation of reactive power in the power-supplying system of a laboratory mixer

Throughout the entire range of sand mixing process parameters the power factor tgφ in a roller mixer can vary but a little, that is why a capacitor battery with constant capacity is incorporated in the power-supply system. Calculation results obtained for the known values of particular power factors were utilised to find the capacity of capacitors making up a three-phase battery. Capacitors with the capacity 6 μF each are connected in a triangle and fitted between the power switch in the roller mixer and the electric motor.

Basing on registered instantaneous voltage and current levels, Fig. 6 shows the relevant power components and tgφ.

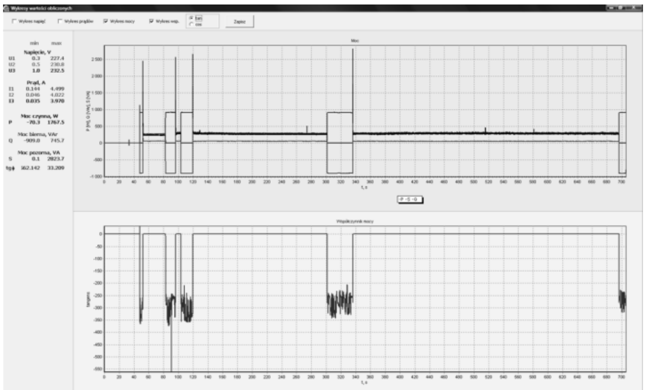

Fig. 6. Window displaying computed power components and tgφ after connecting the compensating battery

When the compensating battery is used, the value of tgφ approaches tgφ=0.2, which is equivalent to cosφ=0.98. The side effect of thus implemented compensation is the enhanced distortion of phase currents. Furthermore, extensive surge voltages and excessive current intensity are registered when the mixer is switched on and off. That effect is the consequence of using condensers only, without any discharging resistors and filters to damp higher-order harmonics.

4. Summing up

Application of the recorder of instantaneous voltage and current levels in a three-phase power-supplying system allows a reliable analysis of power consumption by the given foundry machine.

Measurements taken on a laboratory roller mixer revealed a minor fluctuation of particular power components in the admitted range of sand mix amount fluctuations and for the two considered roller sets. It appears that real tgφ significantly deviates from the admissible levels. Experimental data confirms the necessity to incorporate the battery of condensers with fixed capacities in the power supplying system of the roller mixer. As a result, the costs of electric power shall be decidedly lower, too.

Acknowledgments

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