Mechanism of impulse compacting of moulding sands

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Abstract

A mathematical 3D model of impulse compaction process, developed in the Basic Automation Laboratory of the Institute of Production Engineering and Automation is presented. Experimental and simulation research analysis allowed to determine mechanism of impulse compacting of moulding sands. Mechanism and dynamics of this process evaluated on the grounds of relationships \( p_c = f(t) \) representing time functions of total pressure in the sand layers located at different heights of the compacted sand column. Presented experimental and simulation research proved that developed 3D mathematical model of impulse compaction process of moulding sand describes this process in detail.

Keywords: Impulse compaction process, 3D mathematical model, experimental research, simulation research, Impulse Compacting Mechanism

1. Introduction

The basic compacting method of traditional, bentonite-containing moulding sands is dynamic squeezing. At present, two versions of this squeezing are applied: direct impulse compacting with a compressed-air stream and dynamic squeezing with a plate, e.g. moved by a high-speed pneumatic drive [1–4].

Moulds compacted using dynamic methods are characterised by high quality, i.e. by highly and uniformly compacted moulding sand in the entire mould volume. Such effects of dynamic squeezing result from the mechanism of moulding sand compacting.

Designing and optimising the impulse compaction process of moulding sands requires knowing of mechanism of impulse compacting process, mathematical model and the results of simulation testing of that model.

Theoretical research works related to description of the process of moulding sand compacting, as well as experimental investigation of this process have been carried out for many years in the Laboratory of Basic Automation of the Institute of Machine Engineering and Automation of Wrocław University of Technology (ITMa PWr). Among others, these works contribute to explaining the mechanism of impulse compacting of moulding sands [5–7].

2. Impulse compacting of moulding sands

A diagram of impulse compacting of moulding sand with a single-valve impulse head is shown in Fig. 1.

At the beginning of the impulse compacting process with a single-valve impulse head, the accumulator tank AT is filled with compressed air. The first stage is completed upon reaching the preset value \( p_M \) of pressure in the tank. When the impulse head IH becomes ready to work, the distribution valve DV is actuated with a voltage pulse and the impulse valve IV rapidly opens the tank outlet. As a result, air pressure rapidly increases in the working space above moulding sand. The obtained compressed-air impulse \( (p_I) \) gives the sand a very fast movement and thus a high kinetic energy that is used in the impulse compacting process of the sand.
Fig. 1. Diagram of impulse compacting of moulding sand:
IH = impulse head, AT = accumulator tank, IV = impulse valve,
DV = distributor valve, MB = moulding box, MS = moulding sand, PS = pressure sensor in the mould, CA = charge amplifier,
PC = personal computer

Dynamics of the impulse process can be evaluated, among others, on the ground of the relationship

\[ p(t) = f(t) \]

between pressure in sand and time of the impulse compacting process. This relationship can be also used for evaluating the impulse compacting process. However, the impulse process mechanism can be most easily and completely explained on the ground of a known mathematical model of the process and its simulation examination.

3. Mechanism of impulse compacting of moulding sands

Figure 2 shows the rheological model of moulding sand being a serial combination of viscoelastic models which describe elementary layers of a compacted column of sand. The presented model makes a basis for mathematical modelling of the process of impulse compacting of moulding sands [8, 9].

The process of moulding sand deformation can be described by the following set of differential equations:

\[ m_i \ddot{x}_i + k_c (\delta x_i - \delta x_{i-1}) + k_c (\delta x_i - \delta x_{i+1}) = p_i(t) A + m_i g \]  

(1)

\[ m_1 \ddot{x}_1 + k_e (\delta x_1 - x_1) + k_e (\delta x_1 - x_2) + k_e (\delta x_2 - x_1) = m_1 g \]  

(2)

\[ m_2 \ddot{x}_2 + k_e (\delta x_2 - x_2) + k_e (\delta x_2 - x_3) + k_e (\delta x_3 - x_2) = m_2 g \]  

(3)

\[ m_n \ddot{x}_n + k_e (\delta x_n - x_{n-1}) + k_e (\delta x_n - x_n) = m_n g \]  

(4)

\[ p_{ci}(\delta) = \frac{k_e (\delta x_i(t) - x_{i+1}(t)) + k_e (\delta x_i(t) - x_{i-1}(t))}{A} \]  

(5)

where:

- \( m_i \) – mass of the \( i^{th} \) layer of moulding sand,
- \( x_i \) – co-ordinate of the \( i^{th} \) layer,
- \( p_i \) – pressure in the \( i^{th} \) layer,
- \( A \) – cross-section of the moulding box,
- \( p_{ci} \) – total pressure in the \( i^{th} \) layer of moulding sand,
- \( p_{ui} \) – pressure in \( i^{th} \) layer resulting from compaction of moulding sand.

The equations (1) to (5) have the following meanings:

- Equations (1) to (4) describe the deformation process in moulding sand, respectively in 1\textsuperscript{st}, 2\textsuperscript{nd}, ..., \( n^{th} \) layer.
- Equation (5) describes change of pressures in the \( i^{th} \) layer of moulding sand as a function of time.

Figure 3a shows the relationships \( p_i = f(t) \) and \( p_i = f(t) \), fig. 3b relationship \( p_i = f(t) \) obtained on the ground of simulation examination of the mathematical model, and fig. 3c shows experimentally obtained pressures in the layers of moulding sand.
sand, located at two different heights of the compacted sand column.

![Graph](image)

Fig. 3. Relationships \( p_\text{c} = f(t) \) and \( p_\text{i} = f(t) \) (a), relationship \( p_\text{c} = f(t) \) representing time functions of total pressure in the sand layers located at two different heights of the compacted sand column: simulation (b) and experimental results (c).

Analysis of the relationship \( p_\text{i} = f(t) \) shows the following course of the impulse compacting process: Opening the impulse valve of the head increases pressure in the working space above moulding sand, which moves the sand layers towards the stationary pattern plate. Acceleration of the subsequent layers of moulding sand, starting from the lowest layer, results from transferring to each other the kinetic energy obtained from the forcing agent which is the compressed-air stream. This way, the accelerated stream of moulding sand tending towards the pattern plate becomes more and more compacted, starting from the lowest layer with regard to the pattern plate. The squeezing pressures in individual layers, starting from the top one, are reverse to the obtained movement velocity. The highest ones occur in the sand layers closest to the pattern plate and become lower as the distance from the plate increases. This results from the highest energy of compacting these layers.

The nature of the impulse compacting process in individual layers of moulding sand can be approximately compared to the time-depending step characteristic, i.e. response of a physical object to a stepwise input. In this aspect, the transition component of pressures is a time-dependent decaying sinusoid, and the fixed component is a total of the squeezing pressure \( (p_\text{s}) \) and the pressure resulting from the sand compacting \( (p_\text{c}) \). With this respect, from the point of view of physical system descriptions, moulding sand can be considered an oscillating object [10].

Results of the presented research and their analysis explicitly confirm that the developed serial viscoelastic rheological model permits describing and explaining the mechanism of impulse compacting process of moulding sands.

4. Conclusion

In this work, a mechanism of impulse compacting of moulding sands is presented, based on the suggested rheological model of the process of deformation and compacting of moulding sands, being a serial combination of elementary viscoelastic models. This allows modelling the deformation and compacting process in any volume of the column of compacted sand.

For impulse compacting of moulding sands, the impulse head developed in the Laboratory of Basic Automation of ITMiA PWr was used, characterised by very high internal dynamics that allowed obtaining very good results of moulding sand compacting.

The developed mathematical three-dimensional model permits simulation research of impulse compacting of moulding sands to obtain results for any volume of the compacted moulds. Analysis of the simulation and experimental results evidences that the developed 3D model describes this process very well, explaining the mechanism of impulse compacting of moulding sands.

References

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