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Dedicated to Professor Dr.-Ing. E. Bahke on his 65th birthday

Investigations of a Model for a Circular Bag-Filling Machine for Cement

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Summary

The present paper discribes the development of a model and the agreement achieved with the full scale version of the Claudius Peters Turbopacker bag-filling machine. It is shown that model studies may be of use in improving certain design parameters.

List of symbols

A	cross-section of the filler necks
c	solids velocity
M	torque
$\dot{M}_s$	mass flow rate of solids
n_M	speed of rotation of the model impeller
n_O	speed of rotation of the original impeller
P	power consumption
r_M	radius of the model impeller
r_O	radius of the original impeller
U	peripheral speed
ϵ	air volume/total volume
ϱ	solids density

1. Introduction

Modern mechanical engineering cannot be thought of without also thinking of the laws of similitude. As a consequence of the power required nowadays and the resulting size of the machines, developmental investigations are often performed by using models which are easier to handle and considerably less expensive.

This methodology has long since been established in fluid mechanics, heat exchange and in other fields and continually results in a surprisingly good correspondence when one extrapolates to similar, large-scale, versions. If the physical conditions and the model laws are observed this aid enables one to find solutions to many technical problems at comparatively low expense. The present paper describes the development of a model and the agreement achieved with the full scale version for a cement bag-filling machine.

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2. Full-Scale Plant

2.1 Operating Principles

The turbopacker (Fig. 1) is a compact, high-capacity, filling machine for valve sacks for simultaneous bag-filling and weighing of powdered and fine granular bulk materials. This circular bag-filling machine is usually employed in the bag-filling of cement and lime. For this reason it is installed in cement works or where loading and unloading takes place such as in harbours.

The operating principle of the turbopacker is similar to that of a classic fluid transport machine, but in the turbopacker casing and impeller rotate around the same axis at a different speed. The material is fed directly into the supply tank of the machine. The material level in the supply tank is controlled by a level indicator. Inside the impeller casing a specially shaped impeller rotates at 450 rpm (Fig. 2). Energy is transmitted to the material to be sacked by the impeller which is driven by a 15 kW motor. The previously vertical flow of material is turned into a horizontal flow, and the material is then fed to the valve sacks in the bag chairs through the 6 tangential filler necks.

The material flowing out of the system gap which is necessary for weighing at the slide valve and at the sack valve is collected in dust-separating channels and exhausted via the waste tank.

2.2 Discharge Capacity

The circular bag-filling machine is licensed by the German government calibration department for the range of 25 to 50 kg. The maximum filling capacity is approximately 2,200 bags of 50 kg each per hour. This can be achieved if the bags are positioned by manipulators. Immediately after the bags are in place (Fig. 3) the filling is started. Depending on the given design capacity the filling is finished before the bag reaches the limit switch. When the bag passes the limit switch, pneumatic cylinders cause it to drop onto a conveyor belt. With a maximum discharge of 2,200 bags per hour the mass flow out of each open filler neck amounts to about 6 kg/sec. This is an average mass flow because after a threshold value is reached a switching from coarse to fine flow control occurs by means of induction switches. This is necessary in order to remain within the prescribed weight tolerances.

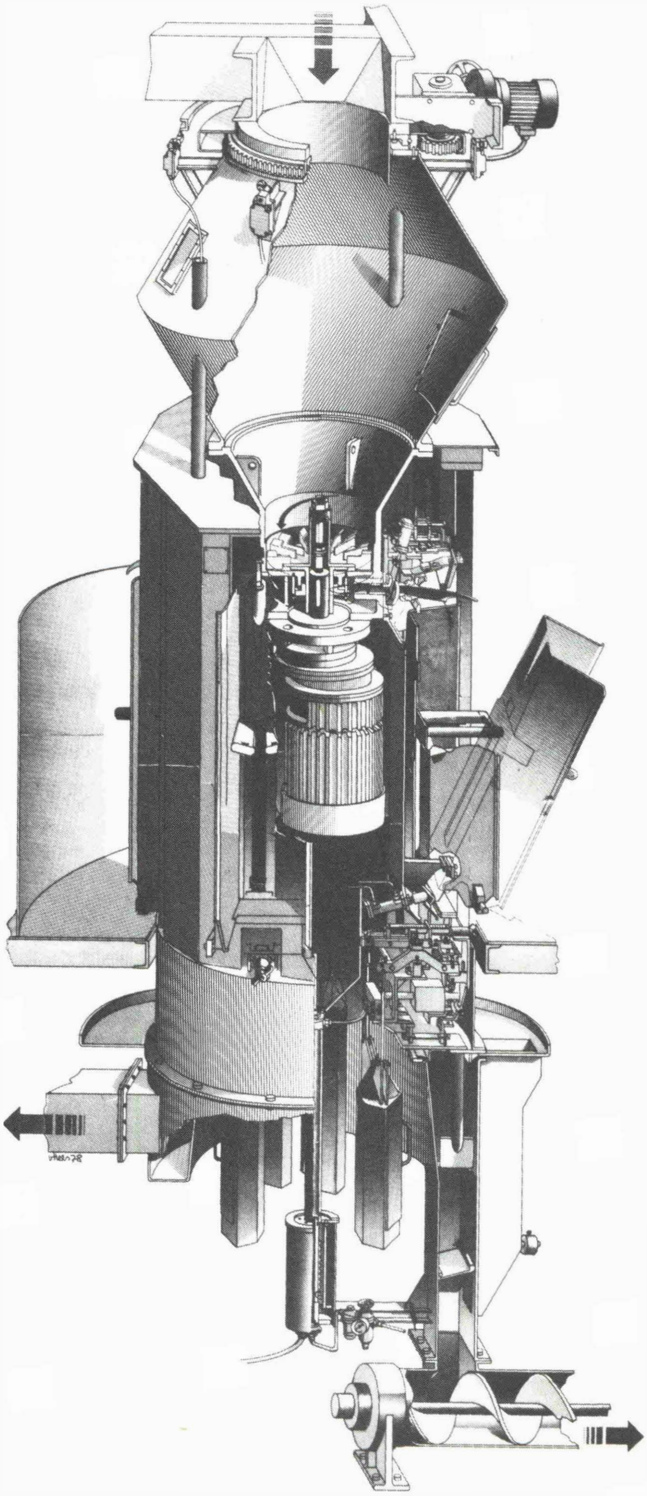

Fig. 1: Sectional view of the original turbopacker (Flow of material indicated by arrows)

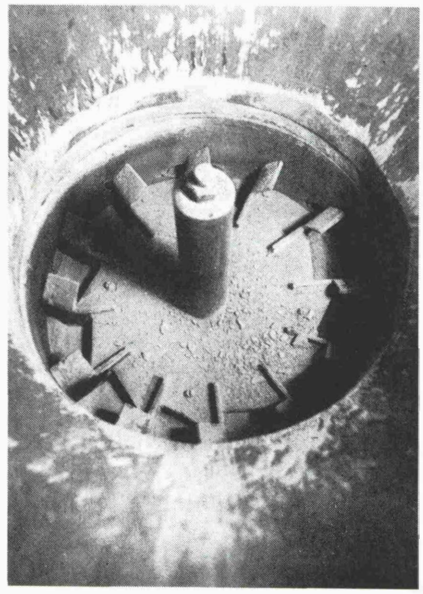

Fig. 2: Original impeller in place

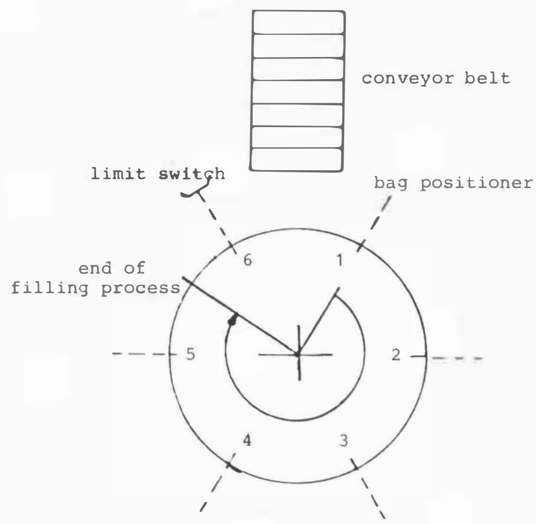

Fig. 3: Filling process

3. Aims of the Investigation

The turbopacker is a well-tried device for the sacking of powdered bulk materials. The aim of the investigation was to gain a more well-founded knowledge about the mass flow from the supply tank to the bags and to test the device under extreme conditions, e.g., using materials with a poor flow behaviour. Based on these tests further improvements of the device could then be envisaged.

A starting point for the investigation was defined according to the following criteria:

a) mass flow as a function of the speed of rotation
b) mass flow continuous or with pulsation
c) required driving power
d) influence of air supply under extreme conditions

All of these points depend on the load range, i.e., on the number of active filler necks because the continuous positioning and dropping of the bags during the filling leads to an interaction between the filler necks.

Based on these criteria an optimization of the device with respect to mass flow, driving power and general behaviour in operation was carried out, without radical modifications of the fundamental geometry, by:

a) modification of the impeller

b) modifications at the filler necks.

These investigations were performed according to the criteria defined above.

4. Model Plant

4.1 Physical Similarity for the Design

The discharge power described in Section 2.2 and the size of the original turbopacker show that a systematic investigation can obviously only prove successful if it is performed using a simplified model, because of the amounts of material handled and the required measuring techniques.

When planning a fluid transport model the following conditions must be satisfied, governed by the laws of similitude:

a) Geometric similarity.
The plant was scaled down to 1:3, i.e., a ratio of length and diameter of 1:3 and a ratio of 1:9 in the case of surface area.

b) Kinematic similarity (similar velocity profiles).

c) Dynamic similarity (similar forces).
Reynolds number = mass forces/viscosity forces = constant.

The speed of rotation of the model impeller ranges between 450 rpm and 1,350 rpm, that is up to three times as high as the full scale impeller. The peripheral speed is assumed to be the decisive parameter in discharge.

$$u = 2\pi \cdot n_o \cdot r_o = 2\pi \cdot n_M \cdot r_M = \text{constant}$$

$$n_M = n_o \cdot \frac{r_o}{r_M} = 3 \cdot n_o$$

The geometrically similar reduction of the exit cross-section means that the exit cross-section of the filler necks is reduced to 1/9. Using the above assumptions, 1/9 of the mass flow of the original turbopacker is expected with a constant peripheral speed, i.e., a speed of the model impeller of 1,350 rpm. Consequently also the exit velocity from the filler necks

$$c = \frac{\dot{M}_s}{(1-\varepsilon) \cdot \varrho_s \cdot A}$$

remains the same provided that the fluidization of the cement is maintained.

The diameter of the impeller is assumed to be the decisive factor in determining the power consumption. Accordingly the geometric reduction leads to a reduction of the momentum to 1/9 of the original.

Consequently the power consumption

$$P = 2\pi \cdot n \cdot M$$

is 1/3 of the original power consumption with three times the original speed of rotation, i.e., with identical peripheral speed.

4.2 Construction of the Model

The main part of the model (Fig. 4) is a simplified and geometrically reduced replica of the turbopacker.

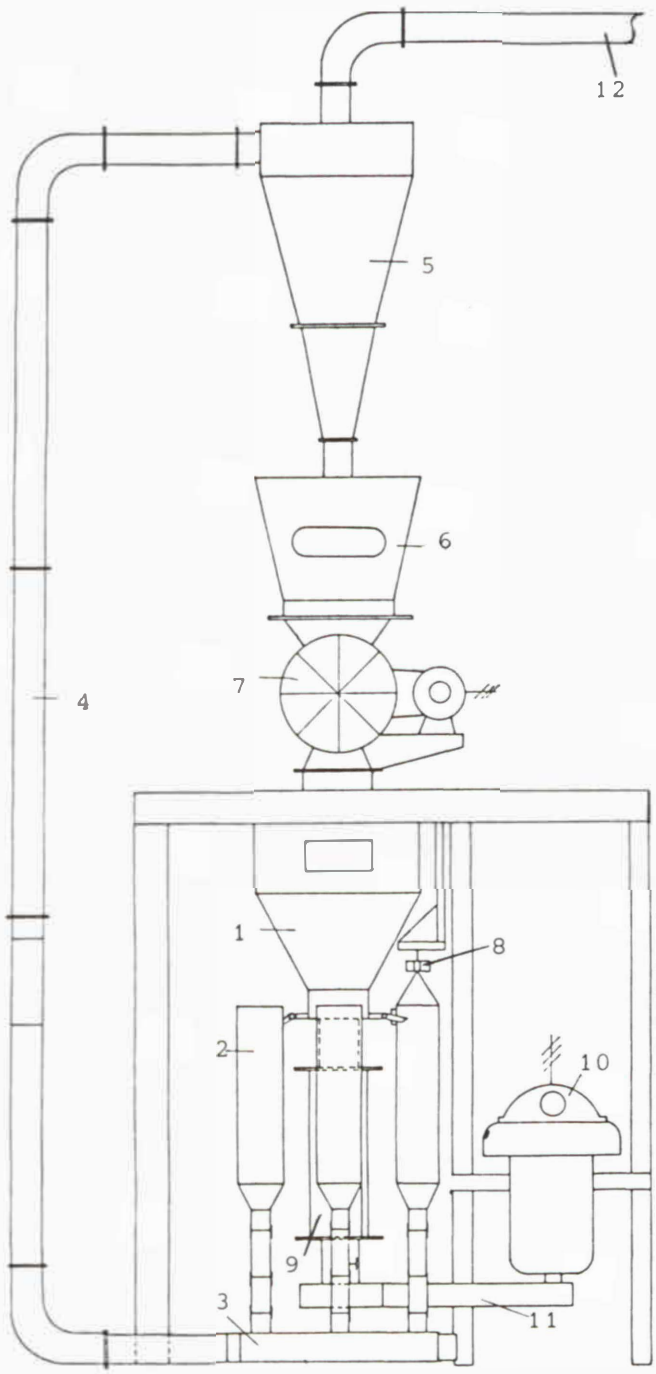

Fig. 4: Diagrammatic sketch of the model plant

1) turbopacker, supply tank, impeller casing with impeller
2) bag simulator
3) annular channel
4) return pipe
5) cyclone precipitator
6) feed hopper
7) rotary valve with continuously variable speed
8) measurement of mass flow
9) bearing of the torque-meter shaft with tacho-generator
10) drive-motor with continuously variable speed
11) belt drive
12) exhaust pipe

The cement flows through the filler necks into the bag simulators. At the top of the bags there is an air outlet; at their bottom they can be closed by flaps. The cement is exhausted into the return pipe by way of the adjacent annular channel and is precipitated by a cyclone into the feed hopper. From here it is fed to the packer via a rotary valve with a continuously variable speed. The exhaust air passes through a bag filter and the blower into the atmosphere.

The mass flow is measured by a load cell. For this purpose the hopper is uncoupled from the annular channel. For measuring the power consumption a torque-meter and a tachogenerator are installed. The measured signals are amplified and recorded on a chart recorder.

The impeller is driven by a motor (5.5 kW, 200—1,500 rpm) with continuously variable speed. The torque is transmitted to the impeller by means of a belt drive, the torque-meter and the shaft of the impeller.

5. Confirmation of the Physical Similarity

If a model is investigated the first necessity is to confirm that the assumptions concerning the physical similarity are in accordance with the test results. If the transfer of results from original to model is confirmed, further model developments can be carried out and one can take for granted that a transformation of the improvements achieved in the model back to the original will prove successful.

In the present example, mass flow and power consumption are the main criteria. According to Section 2.2 the average mass flow of the original plant is 6 kg/sec from each open filler neck. With the geometrical reduction of the model and according to the laws of similitude described above, 1/9 of that mass flow is to be expected with identical peripheral speed. Figs. 5a and 5b show mass flow and power consumption versus the number of revolutions. Each time three filler necks are open. The mass flow increases nearly linearly as the torque increases. At 1,350 rpm it amounts to 0.65—0.75 kg/sec. The power increases parabolically.

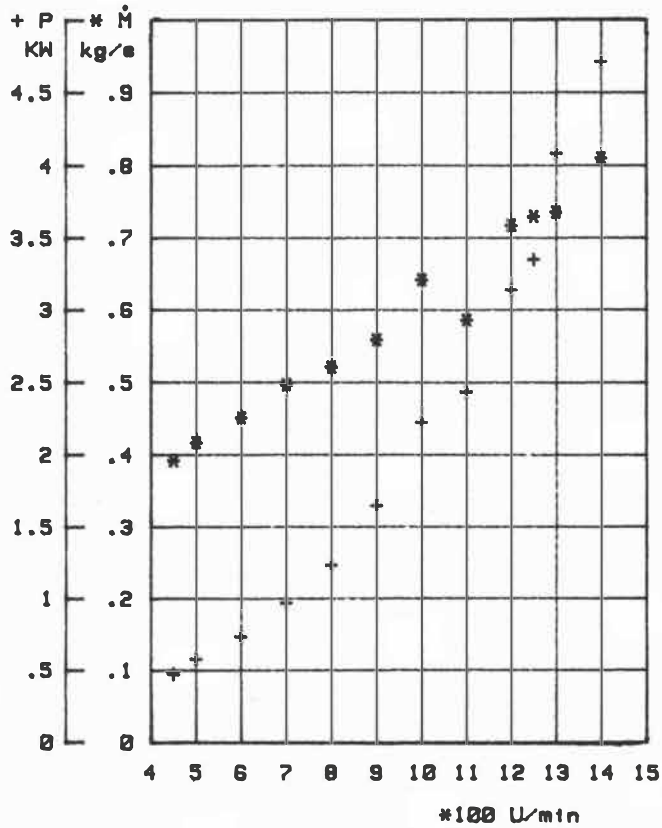

Fig. 5a: Mass flow and power consumption vs. speed of rotation (rpm)

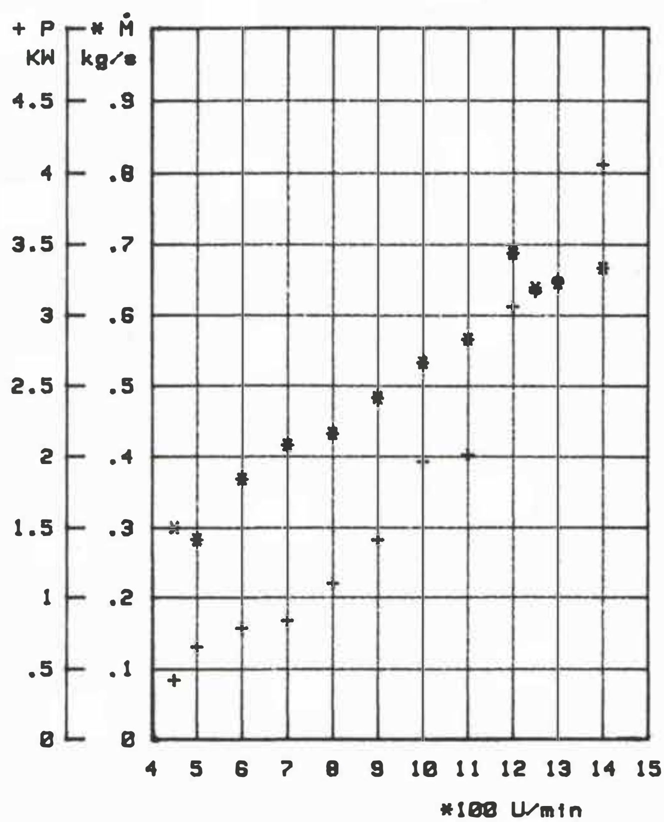

Fig. 5b: Mass flow and power consumption vs. speed of rotation (rpm)

6. Further Developments of the Model

After the model theory had been confirmed by the investigation, more influential factors in the turbopacker model could be investigated at a comparatively low expense. The desired improvements were to be achieved by an optimization in the area of the impeller casing, i.e., at the impeller and at the filler necks. The investigation was performed according to the following:

a) Impeller.
   Influence of entrance angle and exit angle, number of blades and height of blades.
b) Filler necks.
   Position of the filler necks, shape and size of the exit cross-section.

Fig. 6 shows the influence of the exit angle of the filler necks on their length. If only the fluid flow in the pipe is regarded, a shortening of the distances will lead to a reduction of the energy requirement. In this special problem, however, further design aspects need to be considered. A change from tangential to semi-radial exit means a length-saving of 24 % and with radial exit of 31 %. Fig. 7 shows part of an impeller casing and an impeller used in the continued investigations.

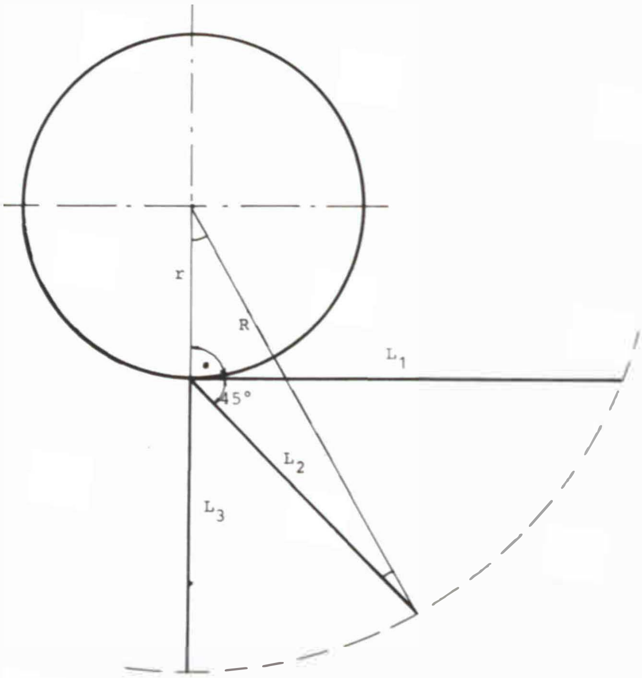

Fig. 6: Variation of the exit angle

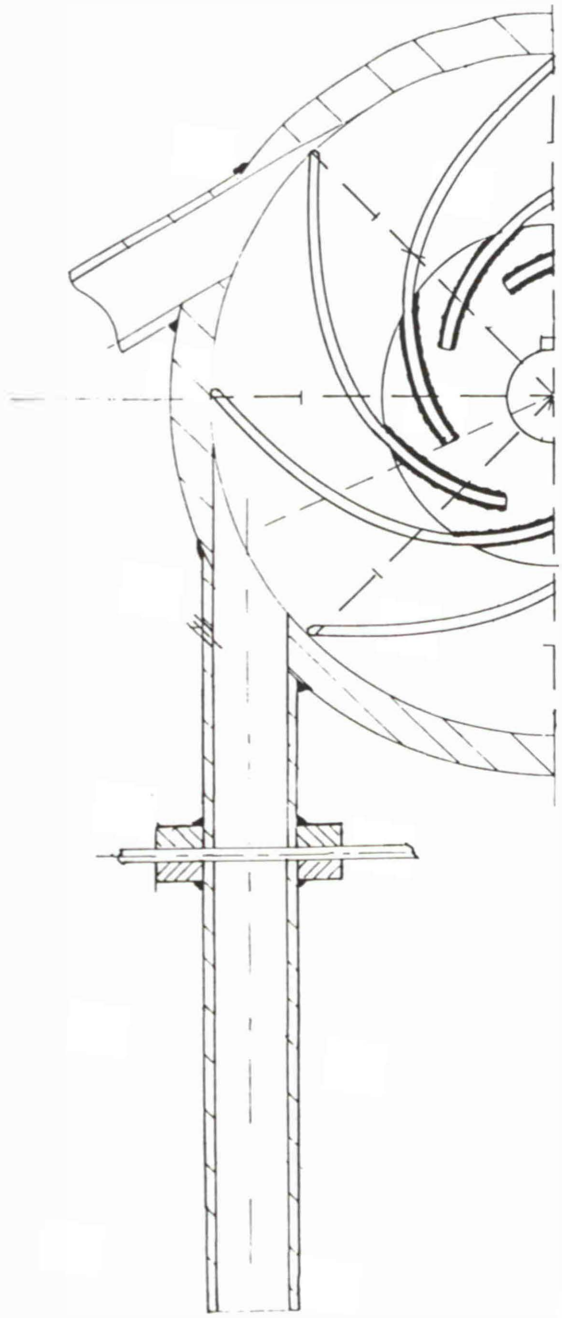

Fig. 7: Example of impeller casing and impeller of the model

By improving the discharge behaviour there will be more time left for more precise proportioning. Therefore the device will meet the requirements of users, whose demands concerning weight tolerances are steadily increasing. Moreover, the plant constructor must find ways to keep up with an increasing demand of the market on the number of bags filled per hour. Of course, these considerations must be related to energy consumption.

At present the improvements developed by means of the model are being tested in continuous operation of the original turbopacker. First experiences have confirmed that a transfer from the model back to the original is possible.

References

[1] Thormählen, P., "Rundpacker mit horizontalem Turbinenrad", Zement, Kalk, Gips Vol. 11 (1978)

Acknowledgements

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