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System for Mechanized Supply of Slag-Forming Mixtures to a Mold in Casting of Slabs with a Very Large Cross Section

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Abstract—We present the design of a new system of mechanized supply of slag-forming mixtures to the mold of a continuous caster during the production of slabs with a very large cross section and the results of studying the energy-force parameters of its prototype. These results support the correctness of our technical solutions and can be used to determine the parameters for a commercial version of the system.

Keywords: slab workpiece, mold, slag-forming mixture, mechanized supply, screw conveyer, drive, torque

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The use of powdered or fine slag-forming mixtures (SFMs) continuously supplied to the metal melt surface in the mold of a continuous caster makes it possible to improve the conditions of ingot surface formation and to decrease the load on the drive of the mold tilting mechanism. The efficiency of using SFM depends significantly on the uniformity of the SFM layer distribution over the free surface of liquid steel [1–3]. This condition is very important for the formation of continuous castings with an extremely large cross section, i.e., slabs the width and thickness of which exceed 2000 and 250 mm, respectively. In this case, a fine material should be simultaneously supplied in two mold zones bounded by its narrow walls and located at the center between submerged refractory nozzles. To meet this condition, the plants designed earlier have paired rigid screw systems 1.5–2 m to provide the supply of SFMs at a given flow rate from two feeding bins to the mold space. These systems simultaneously execute two types of motion in the horizontal plane with respect to the mold walls. For example, in a plant patented in the United States, the feeding nose fixed to the end of a screw tube executes oscillating motion and can also execute reciprocating motion with respect to it. The simultaneous oscillation of the tubes of both screws in the horizontal plane is provided by a double-throw shaft connected to them via rods and rotated by a gear-motor drive. The reciprocating motion with respect to the tube of the screw of the feeding nose is executed by a pusher connected to it by one end, and a roll placed in a profiled groove is fixed to the other end [4]. Owing to this straightening device, a SFM is supplied to the metal melt surface along a straight line, which cannot provide a uniform layer thickness of a bulk material having low fluidity when the slab thickness is large.

In the plant patented in the Ukraine [5], each of the two feeding noses can simultaneously execute reciprocating motion parallel to the narrow and wide mold walls. For this purpose, two feeding bins are located on cars, which are synchronously moved along the wide mold wall with a rack-and-gear mechanism powered by a reversed electrical drive. In turn, a screw weigher is flexibly connected to the lower part of the feeding bin and plays the role of controlled SFM feed using a combined drive. Owing to a crank gear, this weigher executes reciprocating motion in guiding carriers along the narrow mold wall. This design ensures a high degree of uniformity of the SFM (both granulated and powdered) distribution over the free surface of liquid steel in a mold.

During the operation of these plants, a substantial disadvantage, which is related to the absence of rapid switching of the mechanical system from an operating position to parking, was revealed. This disadvantage substantially hinders the work of the staff during the replacement of a failed submerged nozzle, which is repeatedly performed during continuous casting of large steel batches [6, 7].

Therefore, the researchers from the Department of Mechanical Equipment of Ferrous Metallurgy Plants developed a mechanized SFM supply system intended for continuous casters for the manufacture of slabs with a very large cross section [8]. Several new technical solutions were applied to eliminate the disadvantages described above, to decrease the energy consumption of drives, and to build structural mechanisms into the technological equipment of operating continuous casters. The design of these casters does not imply free space for additional auxiliary devices.

Figure 1 shows the composition and the principle of operation of the developed system. It includes hollow

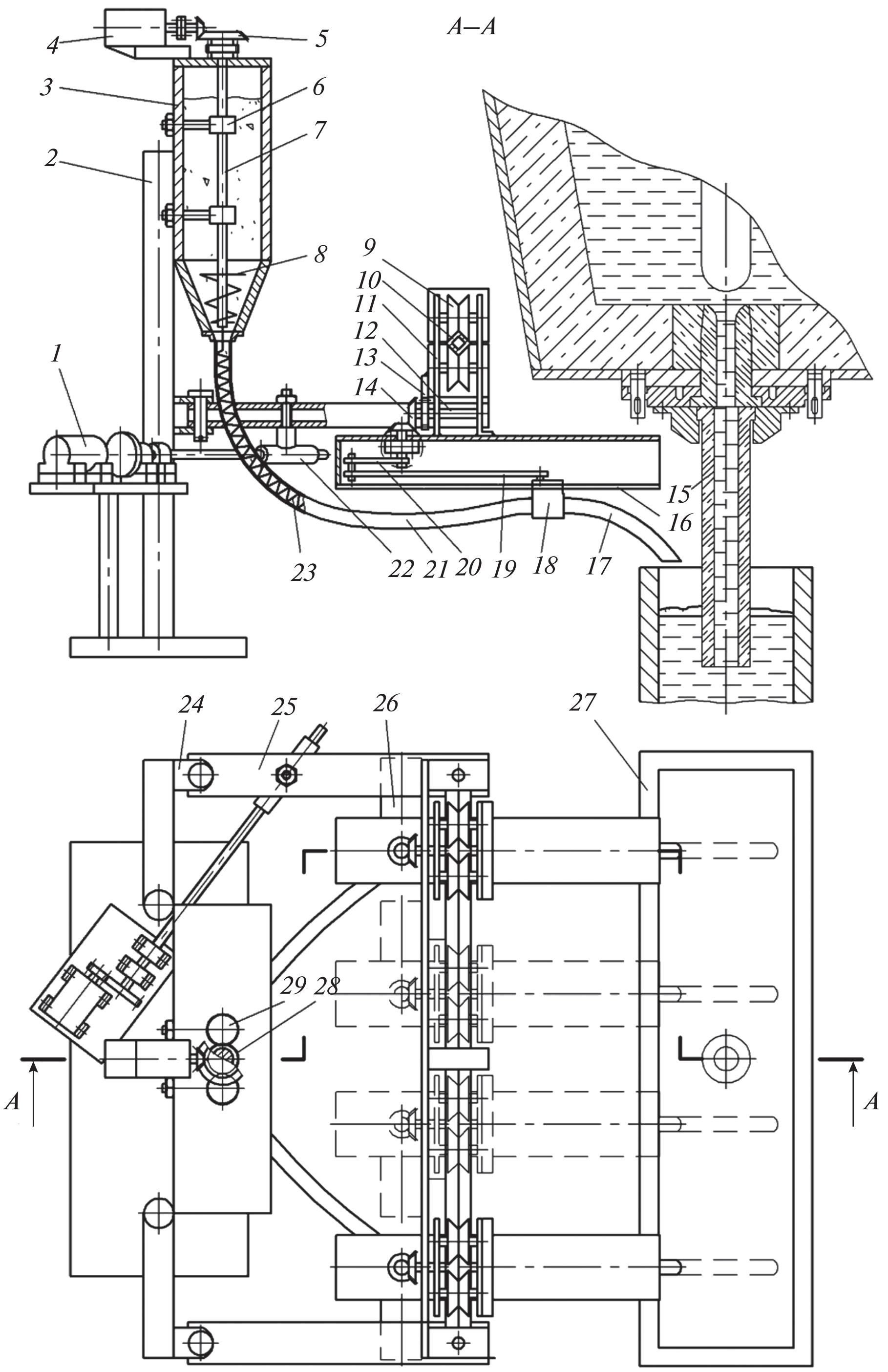

Fig. 1. System of controlled SFM supply to the mold of a slab continuous caster for the production of casings having an extremely large cross section.

beam *10* with a square cross section and rack bar *13*, the ends of which are fixed to two pivot arms *25* parallel to each other along wide mold wall *27*. Hollow beam *10* carriers two carriages *11*, each of which can execute relative longitudinal motion on two pairs of profiled rolls *9* covering contour *10* of the cross section of the beam. This carriage motion through a distance of 0.4–0.45 slab width is executed by a drive, which consists of self-decelerating worm gear-motor drive *26* located on the carriage and two ends of the output shaft situated vertically. The upper end is connected with gear shaft *12*, which is meshed with rack bar *13*, via conic gear pair *14*, and the lower end is equipped with crank *20*, which connected with bar *18* by rod *19*. The bar carries a

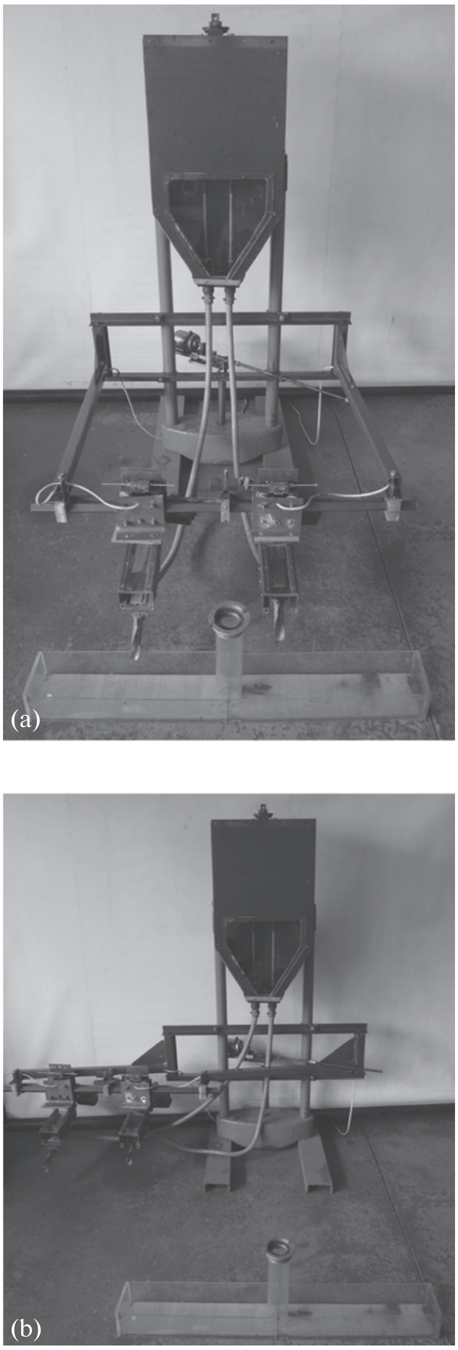

Fig. 2. Prototype of the system of mechanized SFM supply: (a) working position and (b) parking position

feeding nose and can move across in two horizontal guides *16* with respect to the carriage and, hence, the mold. Both feeding noses *17* are connected with feeding bin *3* via flexible metal hoses *21.* The bin is fixed to two supports *2* equipped with arms *24*, which form a parallelogram mechanism along with pivot arms *25* and hollow beam *10*. As a result, beam *10* can execute plane-parallel motion in the horizontal plane with respect to the wide mold wall using drive *1* and screw mechanism *2*. As a result, submerged nozzle *15* can be moved from the mold in a parking position and can be replaced if necessary. The discharge of SFM from the bin at the given flow rate is performed by two rigid screws *8* fixed to the lower ends of vertical shafts *7* located in bearing supports *6* inside the bin (see Fig. 1). Rigid screws *8* are connected with spiral screws *23*, which can rotate in flexible metal hoses *21* over the entire length. Tooth gears *29* meshed with gear *28*, which is rotated through conic gear *5* by gear-motor drive *4* placed on the bin, are rigidly attached to the upper ends of the vertical shafts.

We prepared a prototype of the proposed new system for mechanized SFM supply to test the correctness of the proposed technical solutions and to obtain information on the energy–force parameters of the mechanism drive, which provides controlled supply of a bulk material from the bin and its transportation to the continuous caster mold space.

In testing the developed system, we checked the functionality of its structural mechanisms and the provided accuracy of positioning mobile elements with respect to the mold in the operating position (Fig. 2a) and after motion to the parking position (Fig. 2b). Along with visual inspection of the operation of auxiliary mechanisms, we also measured the technological loads on the drive, which is used for the rotation of the rigid and spiral screw conveyers, and we detected system capacity Q with an electronic balance and a stopwatch.

The torque of the driving engine shaft was controlled with a resistance strain gage transducer, which works along with an amplifier and a 12-digital multichannel L-CARD analog-to-digital converter. Its board was placed in the ISA bus of an IBM-compatible computer. The transducer was represented by the coupling connecting the engine shaft with the conic gear shaft that transfers rotation to both vertical shafts.

The transducer is the sleeve located in slide bearings and placed in a metallic box with a transparent front wall. Resistance strain gages are glued to the sleeve surface at an angle of 45° to the longitudinal axis of the sleeve and are involved in the bridge circuit. The resistance of the foil transducers is 200 Ω. The torque was determined by measuring the torsional strain. Copper rings, the outer surface of which is in contact with the current-conducting busbars the ends of which are connected by a joint built in the lateral box wall, are installed on the sleeve and insulated from its body in order to take an electrical signal from the measuring diagonal of the resistance bridge and to connect a power supply to it.

The processing of the results of gauging the transducer showed that the error of its measurements does not exceed 5%.

Control measurements were carried out according to a deigned plan, which included collection of information on the torques on the drive of the controlled

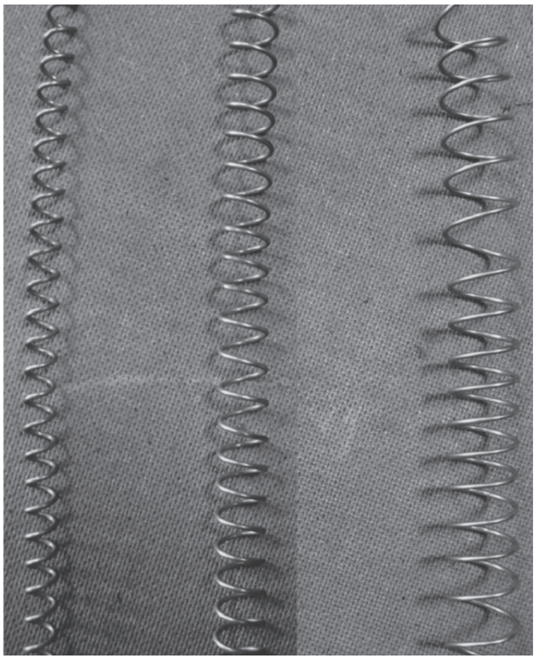

Fig. 3. Samples of spiral screw conveyers.

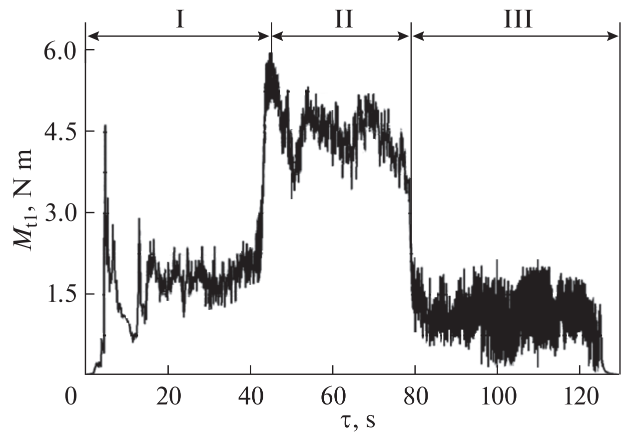

Fig. 4. Change in the drive torque during the rotation of the combined screw conveyer: (I) controlled mixture supply by the rigid screw conveyer from the bin, (II) steady conditions of simultaneous operation of both screw conveyers, and (III) operation of the flexible screw conveyer duiring its discharge.

SFM supply system and on the fractions of the total torque related to the operation of the rigid vertical screw conveyer played a weighing function and the operation of the flexible spiral screw conveyer, which moved the bulk material from the bin to the continuous caster mold through the hose. The separate operation of each of the two combined screw conveyers was ensured by separation of the kinematic circuit of their rotation drive at a certain site. During the experiment, we sequentially combined the operation of the vertical rigid screw conveyer, the turns of the cylindrical part of which had an outside diameter $D_t = 30$ mm and a pitch $S_{tr} = 15$ mm at a shaft diameter $d_t = 20$ mm, with the flexible screw conveyers, the ratios of hose diameter D to the diameter (d_{st}) and pitch (S_{st}) of spiral turns D_h/d_t = 25/18, 20/16, and 15/11 (Fig. 3) and S_{st}/d_{st} = 0.5, 0.7, and 1. Figure 4 shows the characteristic shape of the signals detected during the control of the torque to be overcome by the drive in the course of rotation of the combined screw conveyer at various time periods of motion of SFM from the bin to the mold.

By processing the experimental data, we found that the resistance torques on the flexible (M_{fs}) and rigid (M_{rs}) screw conveyers account for 30–35% and 65–70% of the total torque (M_{t1}) to be overcome by the drive.

We used the drive power (N_1) during the rotation of the combined screw conveyer calculated from the results of control of the total resistance torque to be overcome (M_{t1}) at a given engine rotation frequency (n_{t1}) with allowance for the efficiency of the mechanical system in order to estimate its energy efficiency. To this end, we used the ratio of the drive power (N_1) at a given rotation frequency (n_{t1}) and the corresponding mixture flow rate (Q; Fig. 5). Using this index, we can assign geometric parameters and rotation frequencies to the sequentially connected rigid and flexible screw conveyers, which provide the minimum energy for a technological operation, for designing the system of mechanized SFM supply [9].

Based on the obtained information, we calculated the energy–force parameters of a prototype of the mod-

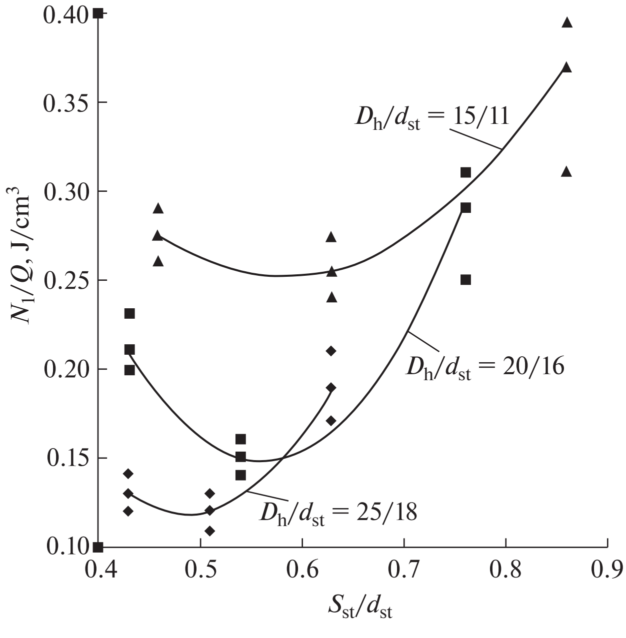

Fig. 5. Change in the specific energy of the spiral screw conveyer at various design parameters.

ified system intended for continuous casters of slabs the cross sections of which exceed 2200 × 300 mm:

Mixture flow rate for one weigher, kg/min	0.3–1.5
Drive power:	
two combined screw conveyers, kW	0.5
carriage motion mechanism, kW	0.15
parking mechanism, kW	0.2

CONCLUSIONS

The improvements introduced in the modified system of SFM supply to a continuous caster slab mold and the recommendations for its design and energy parameters can be used to simplify the maintenance and to improve the efficiency of operation during the production of slabs with a very large cross section.

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