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The system of estimation of the state variables for PWM converter control in the structure of mold oscillation mechanism

The control system of PWM converter in hydraulic drive structure of the mold oscillation mechanism is used for prevent distortions of the mold movement. It is based on collecting data from accelerometers. This system can be useful for many metallurgical plants of Ukraine and overseas where continuous casting technology is used.

References 7, figures 9.

Keywords: *PWM converter; control; mold oscillation; acceleration.*

1. Introduction

Today more than 60 % of slab steel billets are cast on slab continuous casting machines (CCM). These machines make it possible to produce billets of unlimited length with complete uniformity of structure throughout the length. The basis of CCM is the mold – the form, which is cooled by water. The liquid steel flows in the mold continuously. The surface layers of liquid steel are solidified in the mold. It creates the solid shell of billet, which has liquid phase inside. The continuous casting machine and the mold are shown in Fig. 1 [1].

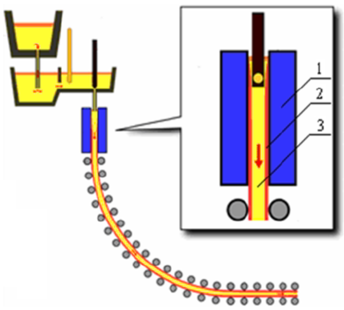

Fig. 1. The continuous casting machine and the mold [1]: 1 – mold; 2 – solidified metal; 3 – liquid metal

The oscillating movement of the mold (Fig. 2) [2] must be performed strictly along technological axis. It is especially important for slab mold. Its transverse displacements must be completely eliminated. Any distortions of movement increase friction forces and stress in shell of the billet. Kinematic and dynamic precision of movement of the mold oscillation table, where the mold is installed, must meet high requirements. When the mold oscillation waveform is distorted because of defects of the mold oscillation mechanism, the stability and safety of casting process decrease, the quality of slab billet surface deteriorates (Fig. 3) [3], and the probability of liquid steel breakthroughs increases. The control system of PWM converter in hydraulic drive structure of the mold oscillation mechanism is used for preventing distortions of the mold movement. Its operation is based on collecting data from accelerometers. This system can be useful for many iron and steel works of Ukraine and overseas where continuous casting technology is used.

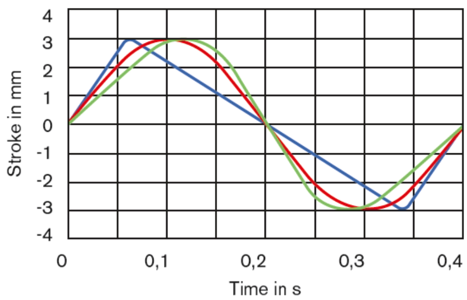

Fig. 2. The mold oscillation waveform [2]

The use of proposed system will increase productivity and lifetime of cast installation, will reduce the maintenance cost and the number of unplanned stops of the production process caused by failures of technological equipment.

Fig. 3. The defects of slab billet [3]

Modern casting machines are equipped with mold oscillation mechanism based on hydraulic drive. Unlike mechanical drive, hydraulic drive makes it possible to implement both conventional

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sinusoidal oscillation modes as well as non-sinusoidal [4].

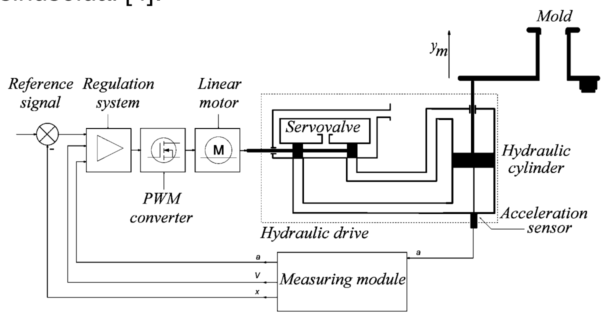

Fig. 4. The structure of mold oscillation system

Fig. 4 shows the structure of casting machine mold oscillation system, where hydraulic drive is a control object. This is a closed loop system with displacement stabilization, which includes hydraulic cylinder, servovalve, linear motor, PWM converter, regulator, comparison element, acceleration sensor, reference signal generator. Servovalve regulates the flow rate of working fluid supplied to the hydraulic cylinder from the oil station (is not shown in the figure). The working fluid moves the hydraulic cylinder. The electric signal of negative feedback from the acceleration sensor on hydraulic cylinder is transmitted to the comparison element, which compares it with the reference signal. Their difference is transmitted to the regulator, which controls the PWM converter of linear motor with permanent magnets. The last one moves the throttle of servovalve and thus carries out the movement of the hydraulic cylinder.

The model of hydraulic drive as a load of PWM converter was considered in detail in [5]. The model of the unit of PWM converter + linear motor as inertial element was considered in [6]. The results of those works were used for synthesis of PWM converter control algorithms, which are formed by regulation system shown in Fig. 4.

Regulation system includes the proportional-integral regulator of servovalve displacement and combined regulator. The operation of the last one may be based on modal control principles and the conception of inverse problem of dynamics or on modal control and use of sliding modes. To implement this algorithm in practice, we should know additional coordinates of the control object – acceleration and velocity. This information is obtained by a measurement system based on measuring the accelerations with MEMS accelerometers.

2. Main body

The system for measuring mold movement acceleration is shown in Fig. 5.

The measurement system makes it possible to keep track of the mold movement and to determine the trajectory deviation from reference signal. The system includes measuring modules (S1-S4) based on three-axis microelectromechanical accelerometers (MEMS), block of data collecting (BCD), personal computer (PC). The measuring modules contains the circuits of signal conversion. The communication between the measuring modules and the block of data collecting is carried out using CAN interface.

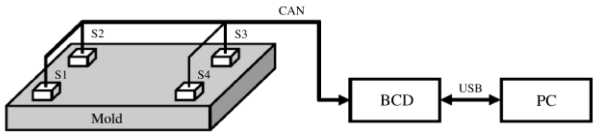

Fig. 5. The measurement system

The structure of the measuring module is shown in Fig. 6. The base of the measuring module is microelectromechanical accelerometer LIS331DLH, which interacts with microcontroller ATmega16M1 by SPI-interface. The microcontroller initializes the accelerometer, collects the acceleration data measured along the three axes, transmits the measured results into personal computer by the CAN interface. The chip PCA82C251 is CAN-transceiver, which provides the matching between the microcontroller signals and CAN-bus according to the standard ISO 11898.

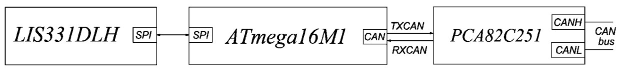

Fig. 6. The structure of the measuring module

The algorithm of the measurement system operation is shown in Fig. 7. Before beginning the measurements, the measuring modules are placed in control points on the mold surface. After starting the system, the initialization of measuring modules and their time synchronization with personal computer are accomplished. Next, the initial static accelerations along the three axes X, Y, Z (the projections of gravitational acceleration) are detected to take into account the installation inclination of the measuring modules (block 1 of the algorithm). After that, the measuring modules S1-S4 are automatically calibrated (the blocks 2-3 of the algorithm). As a result, the zero level for each module axis is adjusted, and the signal gains are found in order to optimal use of the measurement scale.

In the next step, the accelerations are measured by S1-S4 with given discretization frequency. The obtained data are transmitted into PC (the blocks 4-7 of the algorithm). The measuring pro-

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cess terminates when the quantity of the measurements reaches predetermined number. Then, the obtained measurement results are processed to calculate the trajectory of the mold movement (the blocks 8-10 of the algorithm).

The data obtained from BCD after normalizing procedure are processed in PC according to equations (1) and (2). As a result, we obtain the movement parameters of the installation points of measurement modules – velocity and displacement:

$$V(t) = V_0 + \int_{t_0}^{t} a(t)dt\,, \qquad (1)$$

$$S(t) = S_0 + \int_{t_0}^{t} V(t)dt\,, \qquad (2)$$

where V(t) – movement velocity; V_0 – initial velocity; S(t) – displacement; S_0 – initial displacement of the mold surface.

Discrete integration is carried out according to the following equations:

$$v_c\left[(n+1)T_2\right] = v_c\left[nT_2\right] + \frac{u_q\left[(n+1)T_2\right]\cdot T_2}{k_{pr}}\,, \qquad (3)$$

$$x_c\left[(n+1)T_2\right] = x_c\left[nT_2\right] + v_c\left[(n+1)T_2\right]\cdot T_2\,, \qquad (4)$$

where $u_q[(n+1)T_2]$ – discrete function of the voltage, which is proportional to acceleration on discretization interval (n+1); k_{pr} – proportionality factor; T_2 – discretization interval, which is determined by sensor characteristics and tract data transmission; $v_c[nT_2]$ and $v_c[(n+1)T_2]$ – calculated velocity on discretization interval n and (n+1) respectively; $x_c[nT_2]$ and $x_c[(n+1)T_2]$ – calculated displacement on discretization interval n and (n+1) respectively.

To avoid the accumulation of integration error the tracking of specific time moments on the curves of acceleration, velocity and displacement is accomplished. It is convenient to use matching to period or half-period of oscillations because the mold oscillations are periodic. In the time moments, which are multiples of oscillation period, the initial conditions of integration may be considered as zero.

The oscillation period is calculated using mean-value function of difference (MVFD) [7]. The quantity of samples are chosen in the way that two or more periods of oscillations are placed into them:

$$d(mT_2) = \sum_{m=0}^{j} \frac{u_q\left[nT_2\right]}{k_{pr}} - \frac{u_q\left[(n+m)T_2\right]}{k_{pr}}\,, \qquad (5)$$

where j – quantity of values in sample divided by 2.

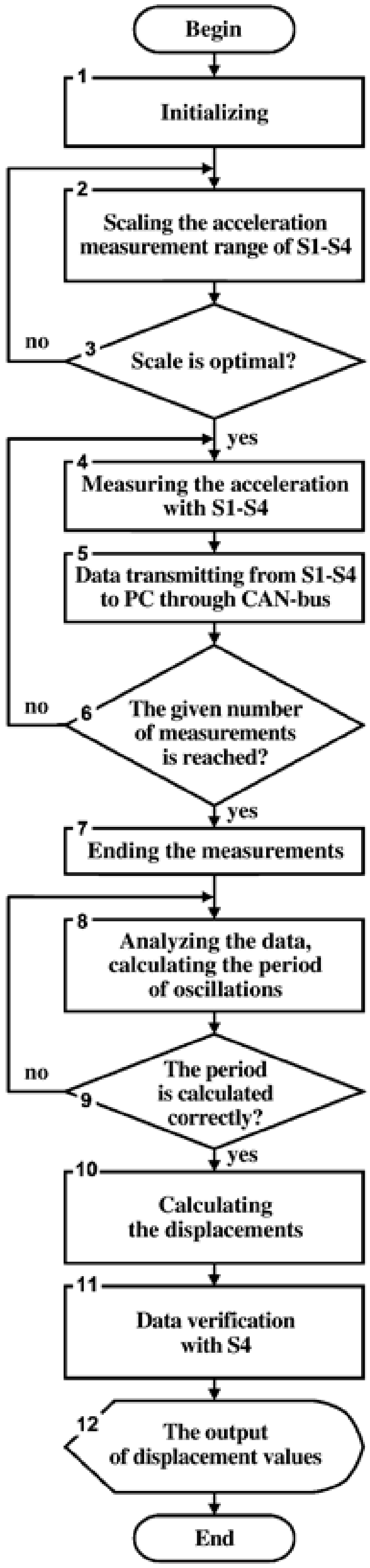

Fig. 7. The algorithm of the measurement system operation

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Further, the minimums of MVFD are determined and the period of oscillations is calculated as a distance between two nearby minimums of the MVFD. The verification of the error absence and the correction of the integration initial conditions in calculating the movement velocity, if required, are carried out by comparison of velocity values in the time moments, which are multiples of oscillation period. After calculating the oscillation period, the integration is accomplished.

The deformations of the mold may be neglected because it is a tough plate. To find out the mold position in space, the data of three points on its surface, measured by S1-S3, are enough. The data from S4 is excessive and is used for verification of correctness of the mold movement trajectory calculation (the block 11 of the algorithm). The verification is performed by theoretical calculation of the fourth point movement trajectory using the information about the three points. The result of calculation is compared with the trajectory measured by the module S4.

The measured and calculated data are displayed (the block 12 of the algorithm) as two-dimensional time diagrams and as a dynamic three-dimensional model of the mold with movement trajectories of the four control points.

The algorithm is implemented in measuring-information system. The system successfully passed the tests at the Alchevsk Iron & Steel Works, PJSC. It was used for monitoring mold oscillation parameters. The basic technical parameters of the system: quantity of measurements per second (1600), resolution (0,5 mg), measurement time (3 s). The output data of the system are accelerations, velocities and displacements from three axes of four measuring modules. As a result of the test, it was found out that the designed algorithm is capable to provide the required accuracy of measurements of oscillation parameters. Thus, if the amplitude of the mold movement is 3mm, the accuracy of displacement measurement for one period of oscillations is 0,025 mm.

The hardware/software module is shown in Fig. 8. The software interface, designed using Python, is shown in Fig.9.

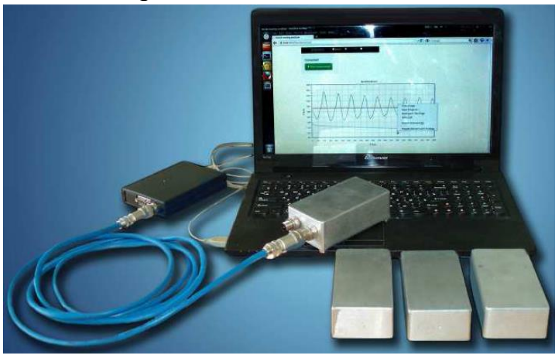

Fig. 8. The designed measuring-information system

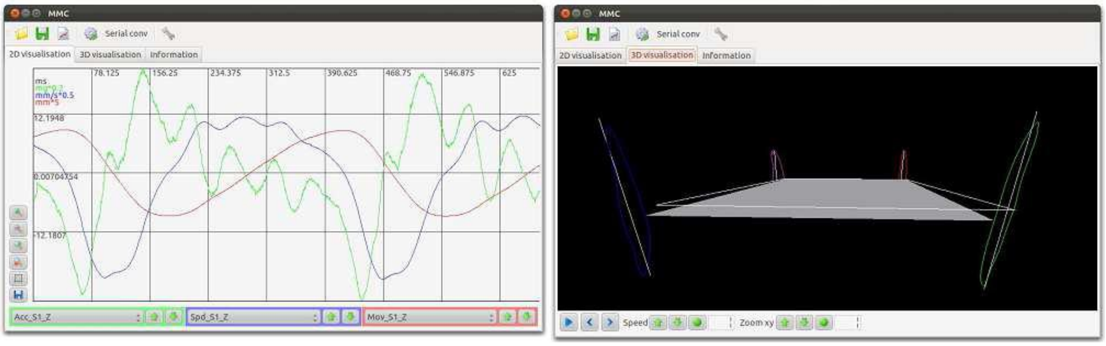

Fig. 9. The software interface

3. Conclusion

The tests of designed system in factory conditions confirmed its operability and effectiveness. It may be recommended for measuring acceleration in a control system of a converter in hydraulic drive of mold oscillation mechanism. The designed system can help to improve the control of the converter, to increase the extent of control automation, and therefore to increase the quality of the product.

In the future, the tests of the developed system in the structure of the mold oscillation mechanism is planned.

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Система оценки переменных состояния для управления ШИМ преобразователем в структуре механизма качания кристаллизатора

Система управления ШИМ преобразователем в структуре гидропривода механизма качания используется для предотвращения искажения движения кристаллизатора. Работа системі основана на сборе данных с акселерометров. Такая система будет полезной для многих металлургических заводов Украины и за рубежом, где используется технология непрерывного литья. Библ. 7, рис. 9.

Ключевые слова: *ШИМ преобразователь; управление; качания кристаллизатора; ускорения.*

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Система оцінки змінних стану для керування ШІМ перетворювачем в структурі механізму хитання кристалізатора

Система керування ШІМ перетворювачем в структурі гідроприводу механізму хитання використовується для запобігання спотворення руху кристалізатора. Робота системи основана на зборі даних із акселерометрів. Дана система буде корисною для багатьох металургійних заводів України та за кордоном, де використовується технологія безперервного лиття. Бібл. 7, рис. 9.

Ключові слова: *ШІМ перетворювач; керування; хитання кристалізатора; прискорення*.

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