AN AUTOMATIC MECHATRONIC COMPLEX FOR ERECTING MONOLITHIC STRUCTURES

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Abstract: Monolithic construction holds one of the leading places in modern civil engineering. All advantages of monolithic construction are fully displayed when using slip forms and erecting high-rise buildings and structures. The most effective application of slip forms is revealed while erecting chimneys, television and observation towers, tower silos, cooling towers, methane tanks, stiffening cores of buildings. Erection of monolithic objects in a slip form provides high rates of construction, good surface quality, continuous technological process, seismic stability of a structure. An important advantage of this construction method is the possibility to automate technological operation. Although nowadays a slip forms automation is mainly reduced to the control of design position, horizontal position of the working floor and automatic control of hoisting jacks. High rates of erecting monolithic structures in a slip form, the possibility of erecting high-rise objects with conic or hyperbolic profile require solution of the tasks to carry out complex automation of slip forms.

Key words: automatic, mechatronic, monolithic construction, building, slip form.

The analysis of slip forms has shown that all of them are controlled complex systems having a number of final control elements and numerous disturbing influences. Complex automation of slip forms is possible by the way of developing on their basis mechatronic complexes with adaptive control.

From the standpoint of control slip forms for erecting objects with variable radius represent a multivariable system with a number of control organs. The position and the shape of the forms as an object of control is determined by the aggregate of external and internal effects. The loading irregularity of the forms working floor, imperfect forms geometry and some other factors result in the forms deflection with respect to the projected axis, the working floor inclination and friction forces change of the forms shields against the concrete. The volume and the tasks of the sliding forms automation is determined by the construction objects appearance, their shape geometrical parameters. The main tasks for sliding forms automation so as to erect object of conic shape are: information-measuring provision to control; the forms mechanical trajectory planning; control of slip forms shields erection and radial displacement; compensations of disturbing effects; adjustment of the forms position.

The analysis of methods and algorithms for slip forms control has shown that attainment of the required accuracy and quality of control over the displacement and shape of the slip forms is possible on the basis of adaptive control algorithms. This kind of control uses the forms models and takes into account the forces acting on the lifting jacks, the forms torsion, thermal deformations of the object being erected, wind loads and a number of other parameters. Mechatronic complexes with adaptive control for monolithic construction must provide monolithic objects erection with deviation of no more than 20mm from the given construction line. The accuracy of radius change must be ± 10mm. The analysis of errors made while controlling parameters has shown that the error of measuring the forms center position must not exceed ± 5mm. and the control accuracy of the jacks position ± 2mm. The complex must keep up the required accuracy under influence of wind loads (at the wind velocity up to 6 m/sec) and thermal deformations. The principle of the mechatronic complexes by the kinematics, design and technological distinctions of the object being controlled, the controls distinctions and also by the character and properties of the disturbing effects. The main distinction of slip forms designed to erect monolithic constructions with variable radius is the availability of two groups of operating mechanisms: lifting jacks (LJ) and mechanisms for radial displacement (MRD). The first of them provide the forms lifting and the second – change of the erected construction radius. Mechatronic complexes should synchronize the work of both groups of operating mechanisms, provide compensation of the main disturbing effects, take into account design and technological limitations.

The developed principles of the complexes construction make up the basis of the functional diagram for mechatronic complex control which is presented in fig. 1. Information – measuring system

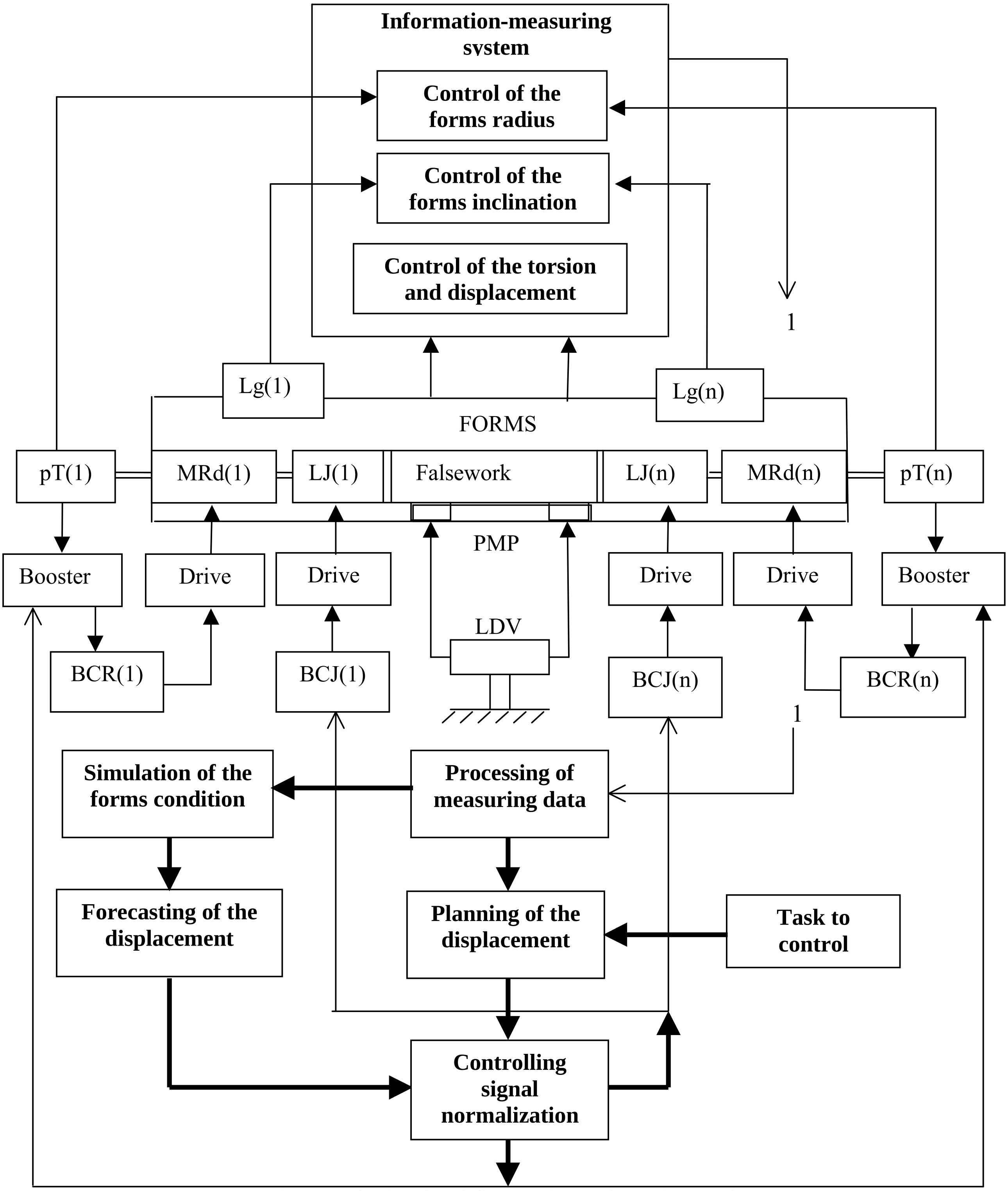

Figure 1.The functional diagram for mechatronic complex

provides control of the main parameters of the mechatronic complex condition. Laser system incorporating a laser set point device for the vertical (LDV) and a photodiode matrix panel (PMP) makes the forms measurements. The system of data processing first scans the photodiode panel PMP about the coordinate axis, records the results of scanning into the image storage area of the photo panel. According to this information boundary values of the photopanel lit area are determined ($X_{min}, X_{max}, Y_{min}, Y_{max}$) and the coordinates of the forms position are calculated relative to the construction lane:

$$X = 0.5(X_{max} + X_{min}),$$

$$Y = 0.5(Y_{max} + Y_{min}).$$

When using two-bean laser control system the values of the coordinates of the beam center on each photopanel $X_{1\min}, X_{1\max}, Y_{1\min}, Y_{1\max}$ and $X_{2\min}, X_{2\max}$, $Y_{2\min}, Y_{2\max}$ become average. The torsion angle of the forms is determined from the relation:

$$\alpha = \mathrm{arctg}(\frac{X_1 + X_2}{Y_1 + Y_2}) .$$

Vertical position of each jack of the forms is controlled by the hydrostatic system of leveling, which is the level gauges equipped with level gauges LG(1)– LG(N), mounted on each jack frame. The coordinates of LG(1)–LG(N) disposition are:

$$x_i = (R - h/\mathrm{tg}\varphi)\cdot\cos(2\pi i/n) ,$$

$$y_i = (R - h/\mathrm{tg}\varphi)\cdot\sin(2\pi i/n) , \quad z_i = h \pm \delta_i ,$$

where x_i, y_i, z_i are the coordinates of the level gauge, *n* is a number of jacks, *R* is the forms radius in the construction base, φ is a slope of the construction, *h* is an elevation mark of the forms working floor, δ_i is a position of the *i*–th jack relative to the working floor. The vertical position of the forms center is determined as an arithmetic mean of the elevation position of z_i jacks:

$$z_0 = \sum_{i=1..n} z_i / n .$$

Measurements of jack frames radial displacements is fulfiled by potentiometric or photoelectric encoding transducers PT(1)–PT(N). The measurement accuracy of these transducers must be ± 1–2mm. When considering the system dynamic characteristics there transducers can be regarded as inertia free links. Measurement data processing allows determining parameters of the mechatronic complex condition and the construction being erected: x_0, y_0 deviations from the construction line, the forms torsion angle α, the forms inclination angle γ, the forms average radius R_h. On the basis of the slip forms dynamic characteristics and disturbing effects a mathematical model of the complex has been developed (fig.2). It makes possible to perform analysis of dynamic characteristics and ecast the forms deviations during the process of its lifting.

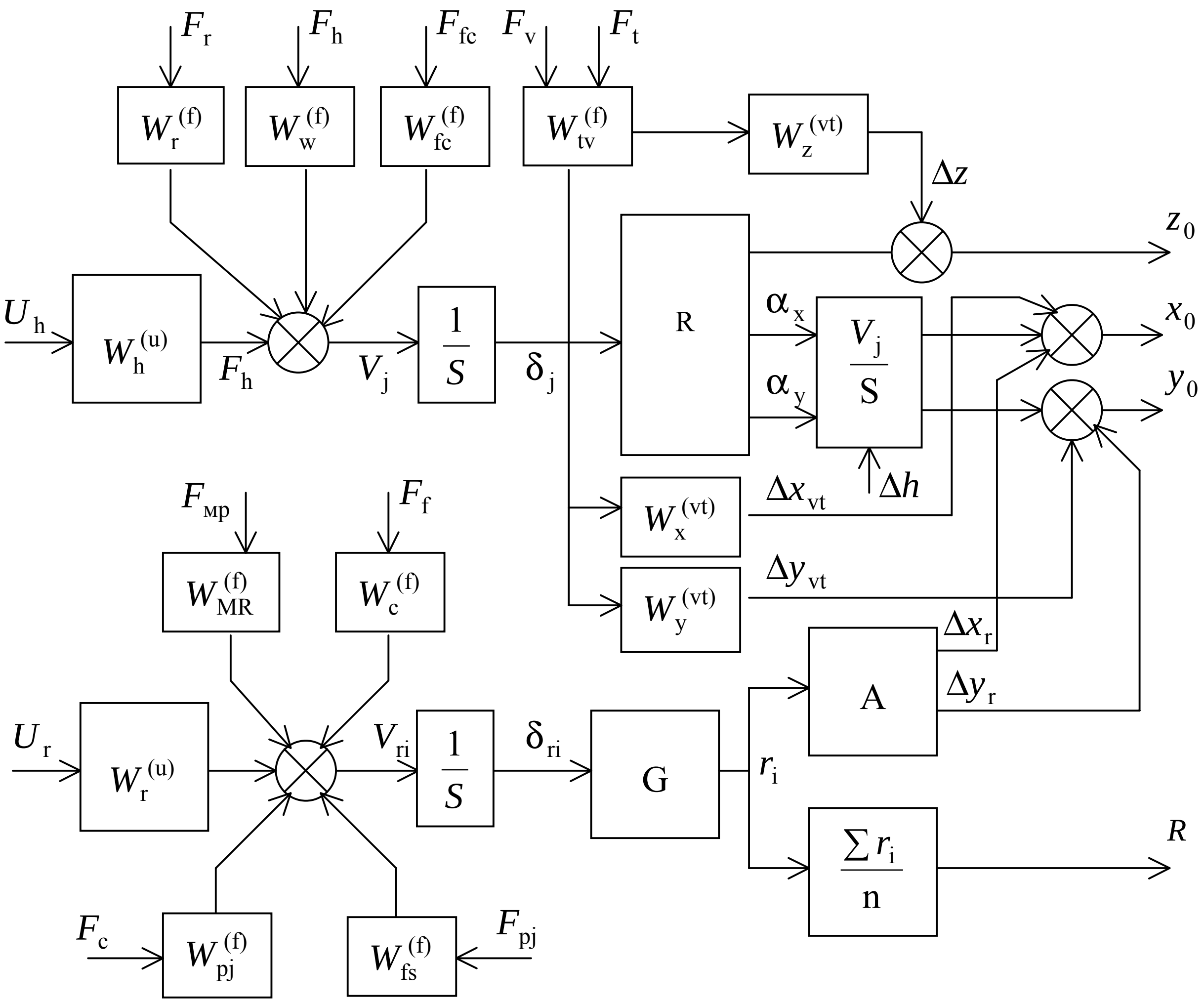

Figure 2. The mathematical model of the mechatronic complex

The mathematical model presents channels controlling the forms lifting and its radius changing, it also reflects connections between then. The controlling effects are voltages of the forms jacks control U_{h} and radial displacement mechanisms control U_{r}. Coordinates of the forms center z_0, x_0, y_0 and its radius R are considered as adjustable values.

While controlling the forms lifting the following external actions are taken into

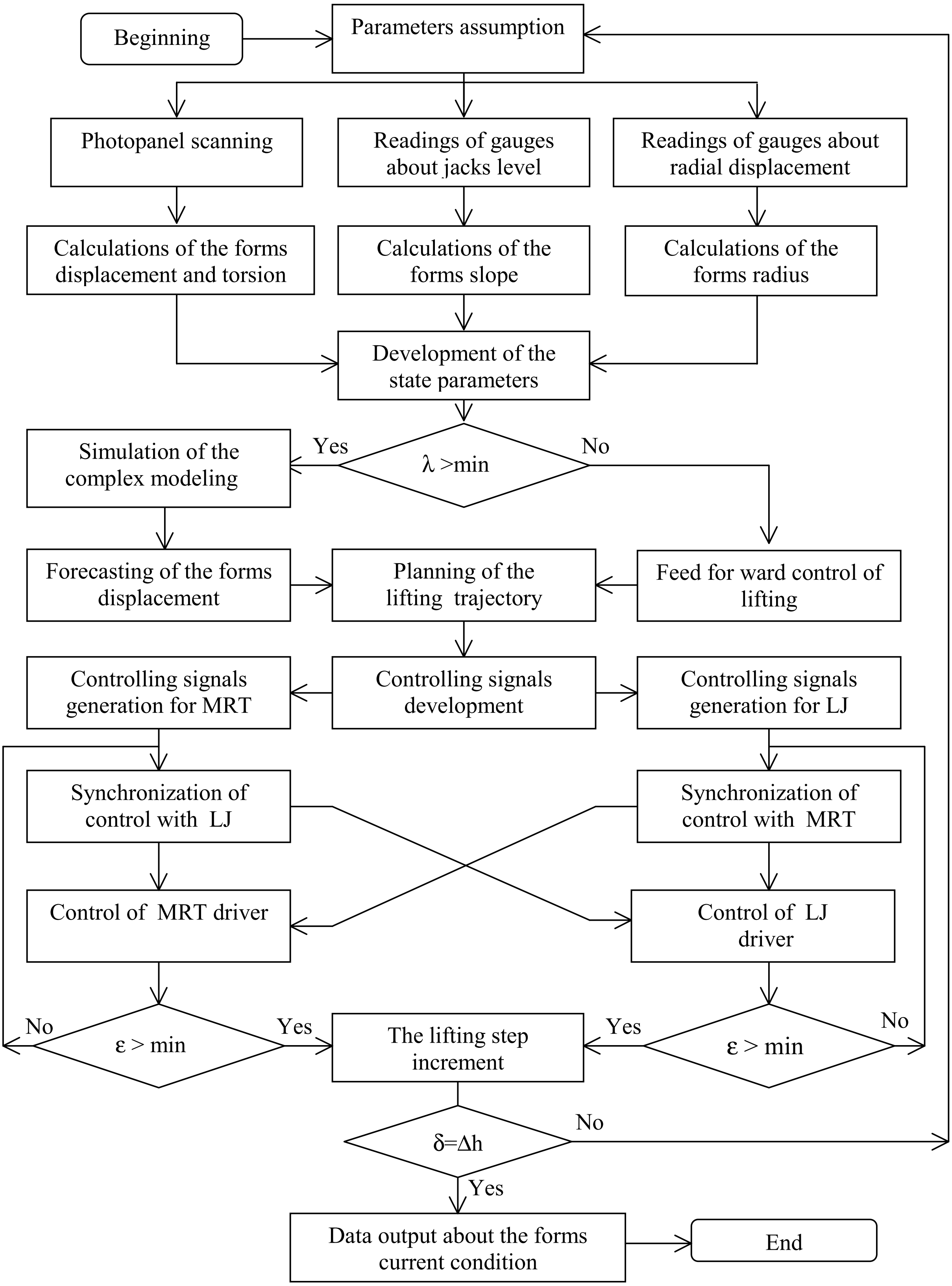

Figure 3. The algorithms for the forms control

consideration: F_r – the pressure force of the lower gripper onto the jack bar; F_w – the forms weight; F_{fc} – friction of the forms shields; F_v – wind load; F_t – additional forces due to thermal gradients. Influence of the force loads on the forms is described by the transfer functions:

$$W_r^{(f)}(s) = k_{fr},$$

$$W_w^{(f)}(s) = \frac{k_{fw}}{T_{fw}s+1},$$

$$W_{fc}^{(f)}(s) = \frac{k_{fc}}{T_{fc}s+1}.$$

Influence of wind and thermal effects on the forms position can be represented by transfer functions:

$$W_{vt}^{(f)}(s) = f_{vt}(s),$$

$$W_z^{(vt)}(s) = k_{vz} + k_{tz},$$

$$W_x^{(vt)}(s) = k_{vx} + k_{tx},$$

$$W_y^{(vt)}(s) = k_{vy} + k_{yz}.$$

The forms jacks displacement on the step δ_i is described by the transfer function:

$$W_h^{(u)}(s) = k_{uh} / [(T_{uh}s+1)s].$$

Coefficients matrix R has the dimensional representation of 3*n and sets up the parameters interrelation. The values of it elements are determined from the formulae:

$$k_{zi} = 1/n,$$

$$k_{xi} = [2\cos(2\pi i/n)]/R_h,$$

$$k_{yi} = [2\sin(2\pi i/n)]/R_h.$$

While simulating the channel of mechanisms for radial displacement the following external effects are taken into consideration: F_{MP} – the mechanism reaction to the displacement forces; F_c – concrete reaction to the shields displacement; F_{pj} – elasticity force of jacks bars; F_f – shields friction force. The influence of these external effects is described by the transfer functions:

$$W_{MR}^{(f)}(s) = \frac{k_{MR}}{(T_{MR}s+1)s}, \quad W_c^{(f)}(s) = \frac{k_c}{(T_c s+1)s},$$

$$W_{pj}^{(f)}(s) = \frac{k_{pj}}{(T_{pj}s+1)s}, \quad W_f^{(f)}(s) = \frac{k_f}{s}.$$

The effect of the controlling voltage U_r on the operation of the radial displacement mechanisms is described by the transfer function

$$W_r^{(f)}(s) = k_r / [(T_r s+1)s].$$

Transformation functions G and A represent matrices of coefficients describing effects of the shields radial displacement on the parameters of the state.

The described methods of control and mathematical modelling make up the basis of algorithms for the forms control (fig.3). The difficulty of controlling a mechatronic complex is connected with the fact that it takes a lot of time to correct mistakes that occur during the process of lifting. Their elimination is only possible after 10–20 steps of lifting. Therefore it is necessary to forecast behaiviour of the complex under control on the basis of mathematical modelling and applying laws of control. The characteristic feature of the presented algorithm is presence of simulteneous processes providing operation in a real time and the mechanisms synchronized control.