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Prospective Electromechanical Control Systems of Industrial Manipulator Efforts

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ABSTRACT

The current electric drive of industrial manipulators is implemented on the principle of speed control and position of the actuator, often donot provide actuator motion as consistent with required process specifications. Taking into account the disadvantages of existing control systems the new approach to control systems engineering and implementation of industrial manipulators electric drives using force balancing systems of actuator efforts control was proposed. Application properties and implementation of efforts control systems inside springy gears and mechanisms of industrial manipulators have been studied. The efficient structure of electromechanical system, which provides the desired balance the transfer object weight and dampening of manipulators mechanical gears springy oscillations is proved. The studies were performed on mathematical modeling and the prototype of industrial manipulators, which confirmed the performance of control system potential structure application and synthesized effort regulator which provide the required performance factor. The potential electromechanical force balancing systems is ably to increase industrial manipulators performance quality, provides transfer and the desired positioning of load directly by operator. Possibility of efficient application the scope increase of industrial manipulators using the potential force balancing systems of efforts control is defined.

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1. INTRODUCTION

Different lift-and-carry equipment and units are applied to improve performance in various industrial sectors, for transportation of stock materials and items to subsequent processing steps or for their storage. Among them we can find the devices to which operation the contact with carried item in its movement and mostly during positioning is required by the worker. These devices can include specific lift-and-carry equipment and balanced manipulators (BM) [1]. These industrial manipulators (IM) supply and extend the scope of application of industrial robots and standard lift-and-carry devices, improve performance of process automation andcomplexes using genetic algorithms [2] and units of microprocessor control [3].

In reality in various industrial sectors IM with electric drive are mostly used due to their maintenance easiness and availability of electric power. Such manipulators are usually applied with items weighing from 100 to 500 kg. The above studied IM type is often used for loading and unloading in the nuclear industry, agriculture, building, trade and service industry. It is possible to transfer load via IM with application of a relatively small force required to overcome the residual force of the load weight item, the friction forces in the joints and supports of actuator [1].

In many cases, the application of manipulators in the machine-building companies can reduce the risk of work-related locoengineium diseases, can improve safety, can increase notably efficiency of production divisions. Among the current industrial manipulators produced in series we can note balanced manipulators ShBM series of domestic production and foreign industrial manipulators Liftronic INDEVA, Italy [4-6].

2. TASK DESCRIPTION

The current electromechanical systems (EMS) of industrial manipulators are designed on the principle of drive rate control of the actuator that has some disadvantages mostly during positioning in a specific point or while moving carried load at the complex load route. For implementation of prospective IM models we propose to apply force balancing systems (FBS) which are used now in engineering of gravity force balancing systems of various items. FBS is widely used in development of simulators for training astronauts to work in conditions of complete or partial gravity [7]. Relating to IM the working principle of electromechanical FBS will be the gravity by partial compensation of its weight as well as friction forces and inertia of added mass [3].

Due to tension of mechanical transmissions and constructions IM [8] helps to increase dynamic loads and to increase output coordinates oscillations particularly in the mechanism of vertical load motion system (VMS) [9]. Therefore, currently used the typical control systems of IM electric drives, often do not provide the desired accuracy of speed modes operation and positioning of carried items due to the presence of elastic connections in the system hardware, the clearances and the kinematic errors of tooth gears [10]. Due to it the development and design of efficient EMS which provide balancing loads by adjusting the damping forces of IM actuator springy oscillations would be prospective [11-12].

3. CURRENT CONTROL SYSTEMS OF INDUSTRIAL MANIPULATORS

Quality and reliable IM operation is largely determined by the design of the mechanism and control system of the actuator, which generally meets the following requirements:

a. Providing the possibility of the motion speed control of load unit;
b. Tapering of manipulator speed without jerks, vibration and subsidence of the load;
c. Acceleration constraint of the drive in the start-brake modes to reduce the dynamic loads in its hardware.

The above mentioned requirements provide mostly electric drives (ED) with continuous and sufficiently precise engine speed control. Nowadays bearingless permanent magnet synchronous motor are often applied in the development of IM [4]. In control systems of electric drives (ED) the feedback of engine speed and current shall be designated [13, 14]. While implementing IM ED the subordinate control systems are often used that are noted for easiness synthesis and setting up, the ability to receive the required control actions for each controlled parameter, by taking into account the limitations of controlled coordinates at a given level.

The subordinate control system of ED is largely made double-loop when internal circuit patterned to the optimum module performs the function of engine current limitation in transition modes andcarries out disturbance attacks at the catenary voltage surge and the speed control circuit meets required process specifications.

While designing IM it is critical to select the fixation points in the working body positioning. The simplest way is to use an electromechanical brake. However, the manipulator actuator has a high flexural compliance and under various excitations it is subject to perform springy oscillations. Therefore, the required accuracy of IM speed control actuator cannot be assured. In this case ED is equipped with a negative feedback to the engine voltage and a positive current feedback which is ably to increase the rigidity of mechanical characteristics and to balance the disturbances caused by the load.

Special aspects of IM kinematics with asynchronous ED controlled with changing the stator voltage cause a number of specific requirements of the control system. If the active load torque on the engine shaft, it is requested to use of one-directional power transmission from the engine to the load manipulator unit, it causes a significant increase of heat losses in the engine which appear while using the parameter mode of speed control. IM control systems with frequency-controlled asynchronous electric drive are designed in the form of an automatic control system with feedback of the engine speed and acceleration, because this structure completely meets the manipulator requirements [15].

4. POTENTIAL STRUCTURE OF THE MANIPULATOR CONTOL SYSTEM

While reviewing the ways of engineering and implementation of IM it was detected that the control task of current manipulators is the speed control and the regulator setting of their control system is fulfilled in terms of the transition process data caused by the change of control action.

Due to the fact that in factual IM the engine connection with the actuator is not completely rigid, so while studding ED systems of manipulators, the allowance of the rigid connection of the engine shaft and the device can lead to significant errors. In reality the mechanical transmissions tension cannot be taken into account when the natural frequency of the system mechanical oscillations is significantly higher than the frequencies acceptable for the electric drive control systems.

Nowadays all manufacturers do their best to make IM of easier design that reduces the rigidity of mechanical transmissions items and causes to increasing the impact of springy connections on their work. However the presence of springy elements (SE) in the mechanical part of EMS leads to an increased variability of its coordinates: raising the dynamic loads of mechanical transmissions and increasing the speed control errors or position of the actuator [16, 17].

While reviewing the approaches to engineering of prospective EMS of industrial manipulators it was detected that it is possible to reduce the impact of emerging springy oscillations and to improve the quality of IM operation while implementing their control system which provides the force control in actuators and mechanical transmission [18]. In this case the control system of IM can be implemented using the force balancing principle and the information of the effort in the item suspension device, its weight and force interactions occurred while the actuator motion [4, 5]. While implementing FBS the engine should develop force equal to the weight of the item, but opposite in direction. To implement such systems we need to be aware of the actuators dynamic loads that it is required to use the highly reliable in operation sensors and to implement the control system of additional feedback circuits. Such method of control is widely used in the development of simulators with force balancing systems for training astronauts and testing space product [9, 19].

Appearing mechanisms of oscillations inside SE (Springy Elements) and dynamic loads in constructions and machinery of IM (Industrial Manipulators) can be limited by ED (Electric Drive). It becomes possible due to the creation of additional force impact with the aid of electric engine, which is interacting with the momentum in mechanical gears of manipulator [20].

Industrial manipulators with FBS (Force-Balancing Systems), providing the static load compensation of object, have the following advantages:

a. keeping the object in suspending conditions without break use;
b. absence of speed assignment block;
c. possibility of significant decrease of operator effort while moving the object;
d. object positioning precision while implementing of such control system depends on operator actions.

Electric drive for FBS installing should maintain the high-accuracy effort executive devices inside SE, which are equal to gravitational force of weight deprived object with different applied forces. Effort system implemented in such way allows realizing the weight deprived object motion due to the inappreciable pressure done by operator. Thus, the main task of ED is to balance the object weight and resisting forces of its motion. Therefore, the object moving will be defined by the effort regulating mistake, what is needed to be minimized via task accomplishing of selection the regulating system efficient structure and parameters synthesis of control devices [2-21].

5. RESEARCH RESULTS

Considered principals of development and implementation ways of IM control systems demonstrated the need of Vertical Moving System (VMS) initiation for IM, which is realizing the high-accuracy effort regulating inside executive elements.

Specific of VMS performance, implemented due to FBS use, is conditioned by the fact that the main task of ED and regulating system is keeping up the effort equals to value of gravitation forces on load, but its moving is realized only under outside impacts done by operator, and not by electric engine.

Taking into account the functioning features of IM and requirements to VMS, the efficient structure of effort regulating system is defined in study [1]. For the benefit of protective function realization for current limiting and stabilization of engine momentum under the influence of different parametrical disturbances, it is necessary to apply the inverse feedback along the engine current. Provision of requested dynamic characteristics of VMS electric drive for IM can be supported by appliance the flexible feedback over the differential coefficient of electric engine angular speed [22]. Technical realization of such corrective feedback can be fulfilled by the differentiation of tachogenerator voltage. It can be described inside VMS control system via the time differencing constant, on the assumption of fact that introduced differential constraint is ideal.

Review of literature [14-23] is revealed that for VMS implementation for IM, using force-balancing principals in the presence of severe requirements for effort regulating accurate, is necessary to have the main feedback on effort inside executive device, and proper information about it can be received via effort sensor.

Relied on the method of control device synthesis task accomplishing, presented in [1-3], the transfer function of effort regulator (1) was founded by the following way:

$$W_{rcg}(S) = k_{rcg}\frac{(T_1S+1)(T_2S+1)}{(T_3S+1)(T_4S+1)} \quad (1)$$

where k_{rcg} – coefficient of effort regulating circuit gear; T_1– T_4 – constants of effort regulating.

Researches on mathematical model and on VMS mock-up for IM were completed when parameter values complied with parameters of manipulator type MP-100. Results of tests are introduced on Figure 1 as momentum variation oscillogram inside springy element ΔM_s while outside impacting M_o.

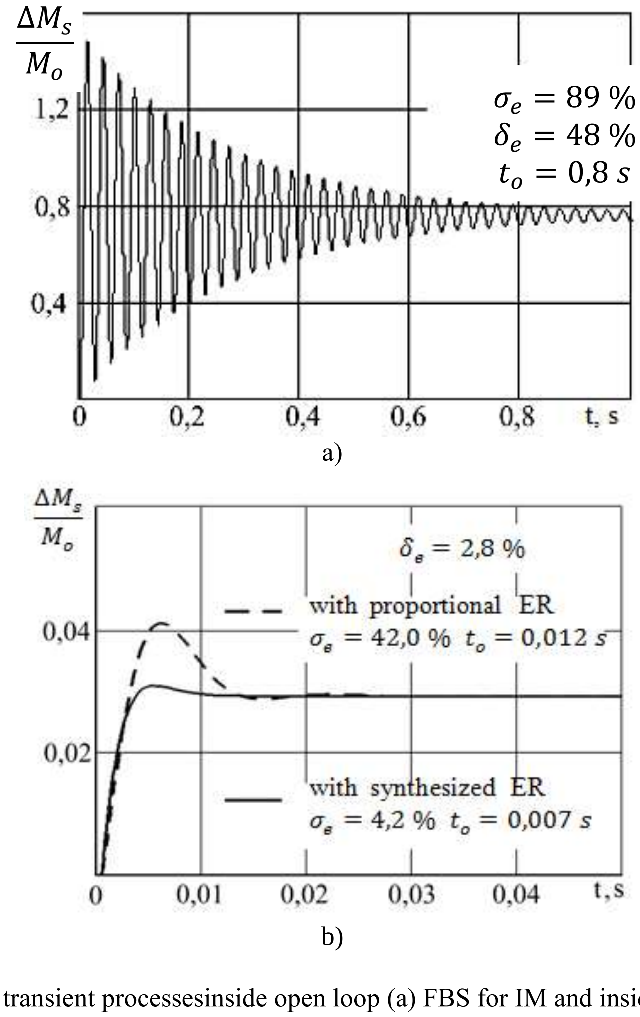

Figure 1. Diagrams of transient processesinside open loop (a) FBS for IM and inside в closed loop (b) FBS for IM with different effort regulators

Analysis of presented transient processes demonstrates that there is an efficient dampening of springy oscillations, and existence of synthesized effort regulator allows guaranteeing the required performance quality inside introduced FBS structure for IM. Overcorrection $\sigma_e$of effort variation process inside SE was reduced from 89% to 4.2%, and established regulating mistake $\delta_e$was also reduced from 48% to 2.8%.

6. CONCLUSION

Realization of force-balancing principal while developing the effort control system of IM enables to define the following advantages which are improving the performance quality:

a. Decreasing of mechanical gear springy negative influence;
b. Operator impact directly on the suspending load;
c. Moving the load in locked position with required accuracy controlled by operator;
d. Easiness of load moving along not pre-defined path.

Application of industrial manipulators with FBS is especially important while working with large-dimension objects which size complicates the positioning vision and requires participation of a few people, owing to the fact that the moving speed and positioning speed is defined and controlled by operator hands via permanent contact with manipulated object. Efficient use of IM with FBS is possibly when there is a need to perform the job with fragile objects, and it is significant to limit the moving speed directly by operator, that allows excluding the probable collision and the breaking of moving products.

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