CONTROL SYSTEM OF ELECTROMAGNETIC BEARING

N. Kodochigov, V. Drumov, I. Drumov, A. Borovikov
I. Afrikantov OKB Mechanical Engineering,
Burnakovsky proezd,15
603074, Nizhny Novgorod, Russia
Tel.: (0 07 83 12) 24 52 88
Fax.: (0 07 83 12) 41 87 72
E-mail: icpokbm@nnov.city.ru

Annotation
In the report some aspects of designing of electromagnetic bearing control system (EMB CS) for a turbomachine mockup, features of system components, hardware and software structure of the control system are described. The individual components of the control system are considered, their purpose is described, the functions, executed by them, principles of construction, organization of interaction of the components are given. Some issues solved at designing and adjustment of individual EMP CS components, such as a selection of computational power of a controller, are described.

Introduction
At the present time OKB Mechanical Engineering develops control system of electromagnetic bearings for a turbomachine [1, 2, 3]. This system shall provide an operation of the turbomachine in all modes.

The system of turbomachine electromagnetic suspension is the complex system, where the results of developments in the fields of mechanics, electronics, microprocessor engineering, software and mathematics are applied. At designing of such system carrying out of calculation - theoretical researches with real simulation of the object is provided for. The real simulation allows developing technology of creation of the large-scale system in a whole, and also its separate components, in particular.

The experimental researches allow verification of analytical techniques and software for certification in regulatory bodies. Besides, they allow obtaining missing data necessary to design of the system of an electromagnetic suspension and a turbomachine in whole.

During designing of of the turbomachine electromagnetic suspension control system it is need to develop the following technologies:
- designing and manufacturing of electromagnetic bearings for a turbomachine;
- designing and manufacturing of rotor position sensors and rotor rotation speed sensors;
- designing and manufacturing of power amplifiers for the EMP control system;
- configuring of controller and control workstation;
- creation of the control programs for controllers and control workstation;
- turbomachine rotor dynamics analysis;
- selection and adjustment of the control and regulation laws for the turbomachine EMB;
- development of compensation algorithms of external effects on the rotor, and also other factors which influence the rotor dynamics, including resonance effects etc.

In order to develop of these technologies the project of the turbomachine EMB includes a creation of two actual models: a turbomachine mini-mockup and large-scale model of the turbomachine. These models consistently solve the tasks of an experimental research. In particular, the mini-mockup allows solving basic issues about system structure, principles of operation and design of sensors, power amplifiers, electromagnets, control logic and their (principles) implementation, the software and hardware. The mini-mockup of the turbomachine is now put into operation.

The turbomachine mini-mockup is a decreased specimen of the turbomachine. Scale of decrease is approximately 1:40. The quantity of electromagnetic bearings is also reduced.

The mass of mockup rotor jointly with sleeves is approximately 7 kg, rotor height is approximately 70 cm, rotor diameter is approximately 2 cm. In one end of the rotor there is electric motor rotor. On the mockup baseplate there are rotor position sensors, stator of the electric motor, and also one axial and two radial electromagnetic bearings. Fig. 1 shows the mockup diagram.

The mockup provides a possibility to study:
- rotor behavior in modes without rotation and with rotation up to 4100 rpm and more;
- levitation and stabilization of a rotor at different initial conditions;
- different laws of a rotor position regulation;
- different variants of control logic;
- algorithms for compensation of external forces which act on the rotor;
- stability areas of electromagnetic bearings, etc.

Hardware and software of the mockup EMB control system, and also some problems which had been solved during adjustment and tests of a mockup are described below.

1 Hardware structure of EMB control system

1.1 Hardware of the system

Hardware structure of the system is shown in Fig. 2.
Hardware of the system includes:
- axial displacement sensors (2 pcs);
- radial displacement sensors for upper rotor part along X axis (2 pcs) and Y axis (2 pcs);
- radial displacement sensors for lower rotor part along X axis (2 pcs) and Y axis (2 pcs);
- rotor rotational speed sensor;
- rotor rotational angle sensor;
- normalizing transducers for sensors;
- controller;
- power amplifiers of electromagnets windings;
- control workstation.

Axial and radial displacement sensors are based on vortexcurrent principle, frequency of sensors generator supplying current is 200 kHz.

Controller is intended to implement of control laws. The main preset regulation law is proportional - integral - differential one with an additional correcting component. The laws and coefficients of regulation and other parameters of adjustment are set by an operator from the workstation.

The power amplifiers of electromagnet windings are intended to control a current in electromagnet windings according to control signals coming from the controller.

The control workstation is intended to supervisory control and data acquisition of EMP operation, the rotor position, other EMP parameters. The control workstation also fulfills functions of the information - measuring system: measurement, displaying and datalogging during EMP tests.

1.2 Selection of the controller configuration

During designing of the control system the following requirements were imposed to the controller:

- the cycle time of control action shall be not more than 500 microseconds;
- amount of input analog signals shall be not less than 12 pcs;
- amount of output analog signals shall be not less than 12 pcs;
- possibility to change coefficients of regulation and other parameters from the control
- workstation during EMP operation;
- diving of the data on rotor parameters and state of the control system to the control workstation;
- diagnostics of a functioning correctness.

For realization it An modular IBM - compatible controller in the basis the ISA - bus was selected o implement the configuration. The controller contains:

- a processor card based on the Pentium 133 processor, containing RAM of 32 Mb, two ports of the RS232 interface, CMOS - memory, watchdog timer;
- 32 Mb flush - disk with the control program;
- 16 - channel input analog card;
- 16 - channel output analog card.

Main problem during configuration is meeting the requirement to the controller rate. Proceeding from this requirement, the processor clock frequency and the type of the input analogue card were selected. The rate estimation was made on the basis of a preliminary estimation of time intervals necessary for implementation of the control program algorithm.

The control program algorithm functioning includes a measurement of input signal values, a transformation them to physical magnitudes (process of scaling), a filtration of input parameters, a calculating of output signals values for control of an electromagnet windings, sending them to power amplifiers.

The analyses show that total number of elementary mathematical operations for implementation of control functions is approximately 800.

Table 1 shows time intervals necessary for execution of adding and multiplication operations of two 32-digit numbers, and also maximum values of the rotor rotation angle which are appropriate to these time intervals with a condition of maximum possible rotational speed (6000rpm). These values were received during testing of execution time of 10 mln adding and multiplication operations, which had been executed by computers with different computational capability.

Table 1: Characteristics of computers with different computational capability applied to given task.

Processor type	Clock frequency, MHz	RAM, Mbytes	Rate, Mop/s	Time for 1 operation, mks	Time of control cycle, mks`	Rotor rotation angle, degrees
Pentium II Celeron	400	128	30.333	0.033	166.96	6.01
Pentium	133	32	5.688	0.176	327.12	11.77
80486DX2	100	8	1.583	0.631	836.72	30.12
80486DX	50	8	0.839	1.192	1465.04	52.74
80386DX	40	8	0.215	4.651	5339.12	192.20
80386DX	33	2	0.205	4.878	5593.36	201.36

The MicroPC 5066 card manufactured by Octagon Systems corporation, USA was selected for the controller. It contains the AMD586 processor with the clock frequency 133 MHz. The time of control cycle will be approximately 327 mks for this card.

2 Software structure of the EMP control system

2.1 Software configuration

The software of the control system consists of:
- development tools;
- a controller software;
- a control workstation software.

The development tools allow creation of the data acquisition and control software. The controller's software is developed in accordance with the specifications of the standard of an International Electrotechnical Commission IEC 61131 on the language of functional block diagrams (FBD). The control workstation software is developed in the language of visual programming (G-language).

The controller software consists of a controller operation system and a control program.

The controller operation system ROM-DOS is MS-DOS - compatible system adapted for the MicroPC - controllers. The ROM-DOS operation system together with the basic input-output system (BIOS) of the controller provides serviceability testing and control of individual hardware components of the controller, and also carries out launching and control of executing of the control program.

The control program of the controller provides regulating a current in windings of the electromagnetic bearing under the preset control laws depending on a rotor position.

The control workstation software provides switching on and switching off of the regulators, setting up of regulation coefficients and other parameters of control. Besides, the software provides data acquisition, displaying and datalogging of a rotor position and rotation speed, control system state and electrical parameters (currents in windings of electromagnets, etc.).

2.2 Software structure

Overall structure of the EMP control system software and the directions of information flux are represented in Fig. 3.

Main part of the EMB control system software, and also EMB itself, is the control program installed in the controller.

The control program contains six independent channels of the rotor position regulating:
- X of a upper radial EMB;
- Y of a upper radial EMB;
- X of a lower radial EMB;
- Y of a lower radial EMB;
- Z of a large axial EMB;
- Z of a small axial EMB.

The structure of the control program is shown in a Fig. 4 on an example of the regulator along upper radial EMB X-axis.

Conclusion
Now, the described control system is implemented on an operating mockup. The mockup helps to carry out researches, necessary, finally, to design an electromagnetic multi-support system of the GT-MGR turbomachine EMB.

Test results show a correctness of basic provisions of the accepted approaches to designing of an EMB control system.

During researches the rotor was levitated and was stabilized relative to all axial and radial bearings in modes with without rotation and with rotation up to 4100 rpm in normal and inverted positions. The system allows investigation of the factors, which influence the amplitude of rotor oscillations, stability areas of bearings, influence of external factors on a rotor position and amplitude of its oscillations.

The mathematical model of a turbomachine rotor is refined, analysis techniques are being verified on he basis of experimentally obtained data.

Upon the whole, test results on the mockup allowed development a number of elements of designing and adjustment technologies of a EMB multi-support system, obtaining of data series for calculating - theoretical works concerning the plant, that increases quality of design.

References

1. Kiryushin A.I., Kodochigov N.G.: The Russian technological developments in support of the international project of GT-MHR plant for utilization of weapon plutonium. The 7-th annual International political forum on nuclear materials. USA, Washington, September 5-8, 2000.
2. N.N. Ponomarev-Stepnoy, E.S. Glushakov, V.N. Grebennik, A.I. Kiryushin, N.G. Kodochigov, N.G. Kusavkov.: Possibilities of use of modular helium reactor GT-MHR for disposion of weapon-grade plutonium. ISSN 0869-6772. Conversion in machine building of Russia.. 1999. №3-4. (in Russian)
3. Arkal Shenoy. US History of Direct Cycle Gas-Turbine HTGRs. Presented at IAEA Technical Committee Meeting on Gas Turbine Power Conversion Systems Meeting/ November 15, 2000.

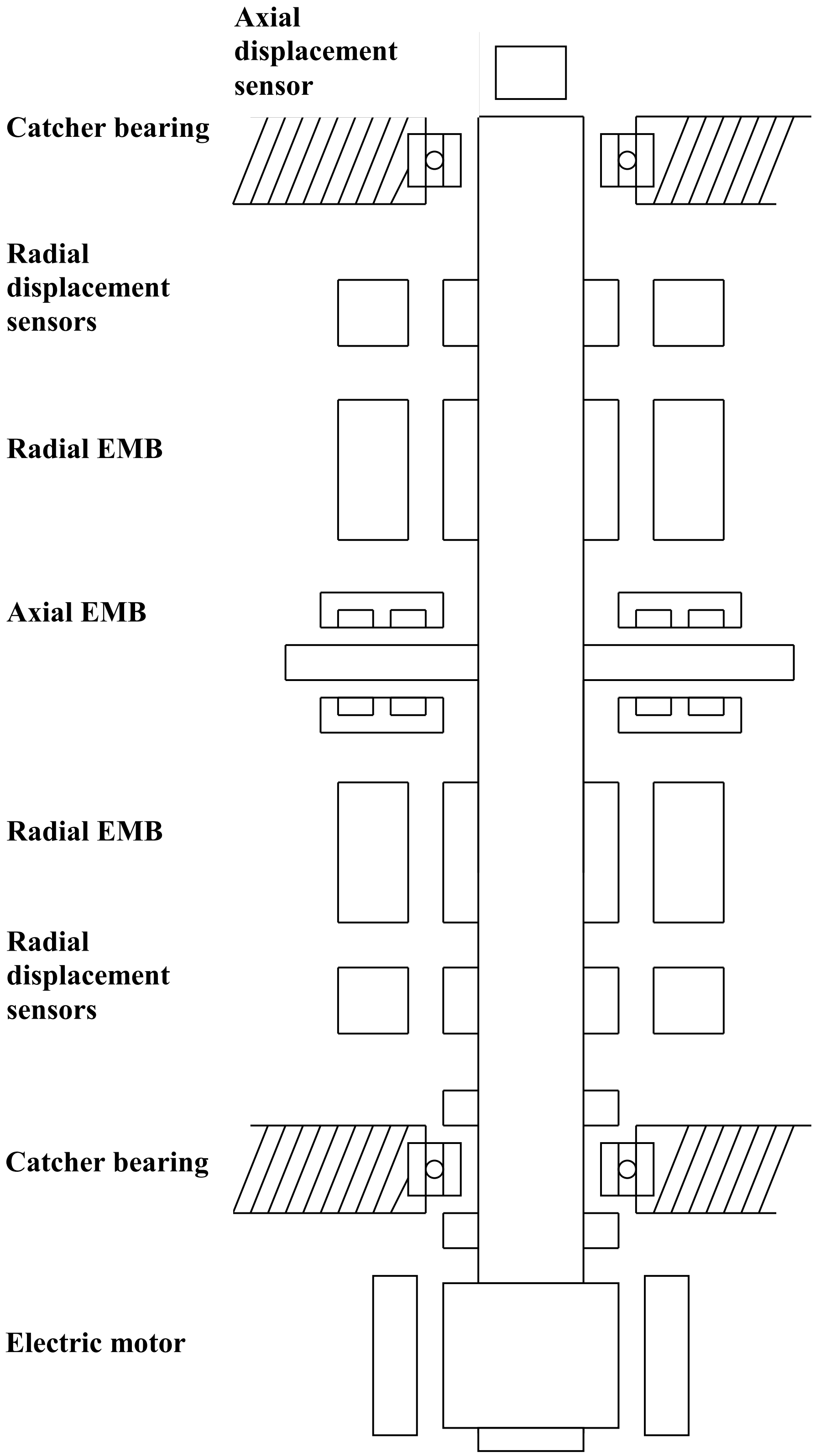

Fig 1 – Turbomachine minimockup diagram

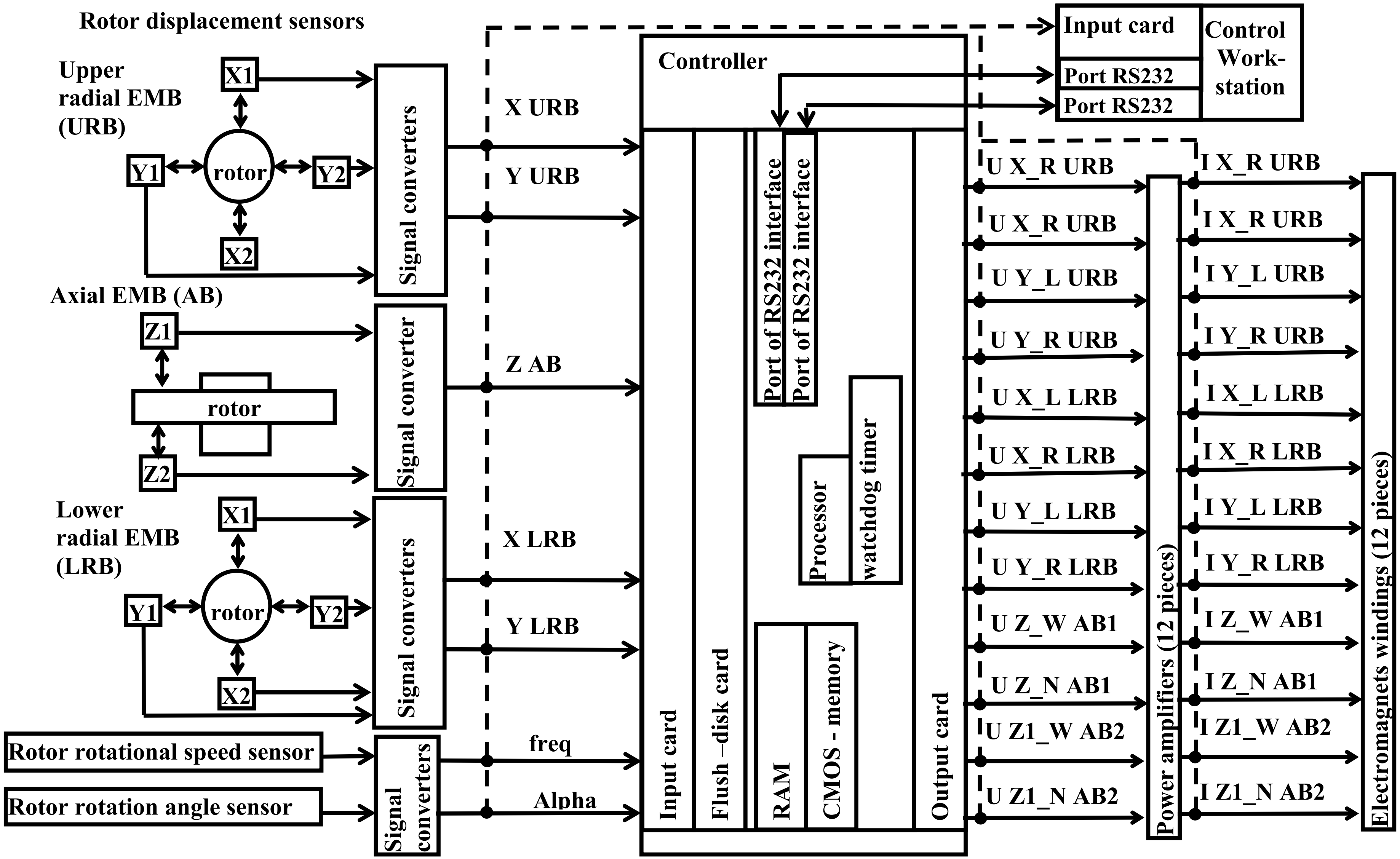

Fig. 2 – EMP Mimi-mockup control and monitoring hardware. Common structural diagram

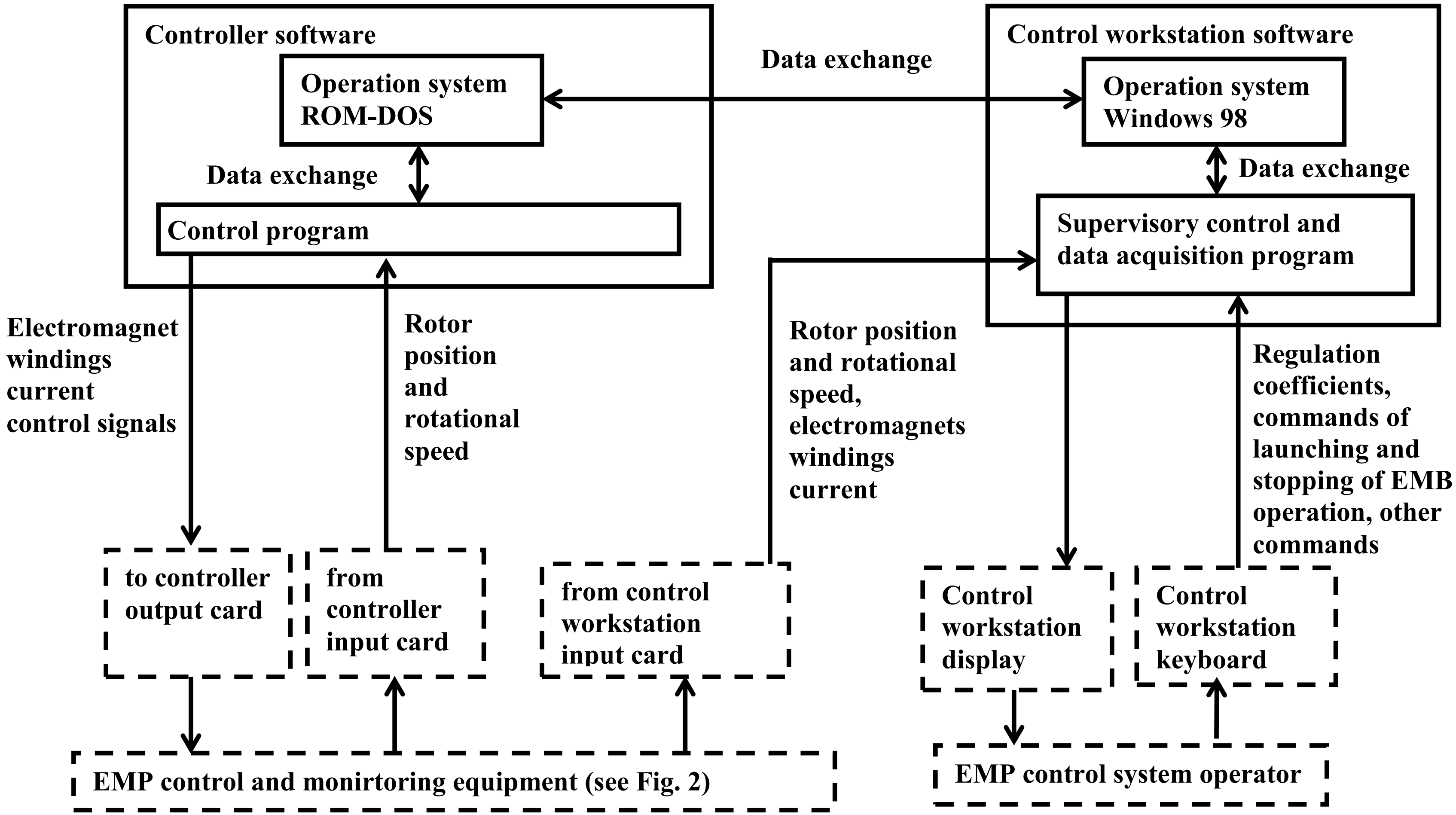

Fig. 3 – EMB control system of mini-mockup. Overall structure diagram

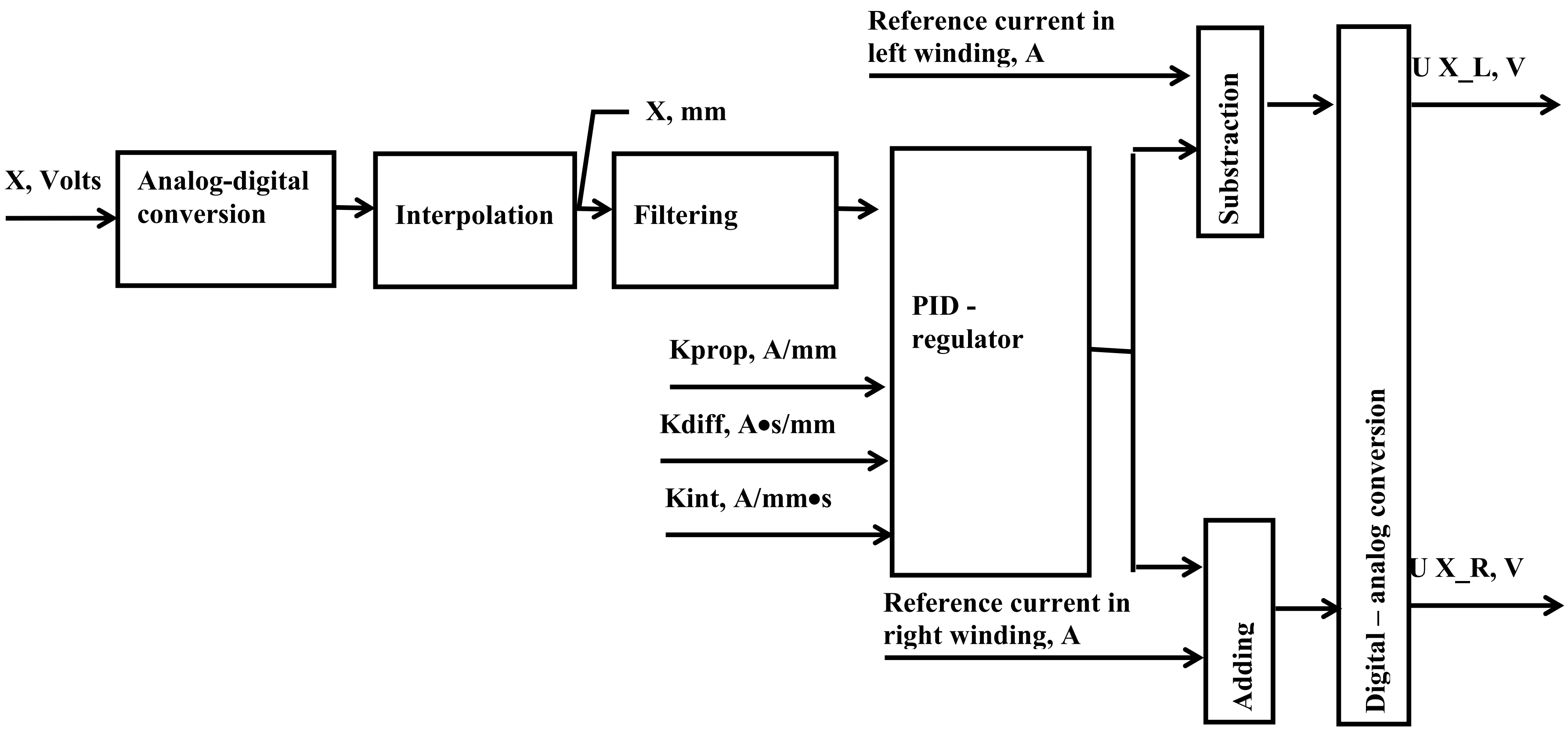

Figure 4 – Software of one regulation channel, example for radial bearing