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TELEOPERATED SYSTEMS FOR NUCLEAR REACTORS INSPECTION AND MAINTENANCE

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Abstract

The present paper describes author's work in the field of teleoperated equipment for inspection and maintenance of the RBMK technological channels and graphite laying, emergency operations. New technological and design solutions of teleoperated robotic systems developed for Leningradsky Power Plant are discussed.

1. Introduction

This paper is one from the series devoted to nuclear power plant reliability and safety improvement with the help of teleoperated and automatic manipulative systems providing inspection and maintenance of RBMK reactor channels. The same robotic systems could be implemented in case of severe accidents at nuclear energy objects and for other technical applications (chemical industry, space, military technologies, etc.)

Main components of the system under development:

- robot for fuel assemblies handling;
- advanced teleoperated / automatic sensor-based manipulator for the reactor hall;
- teleoperated / automatic mobile manipulator for the under reactor zone;
- remote inspection system for technological channels;
- technological manipulative system for graphite laying repair;
- underwater robotic system for the nuclear fuel storage pool;
- remote inspection system for pipes and tubes of the first reactor loop diagnostic;
- mono and stereo TV systems;
- heavy duty crane for the central hall.

All these remotely controlled systems could be considered as cybernetic environment (under the human operator supervising) providing inspection, maintenance and emergency operations in the central hall, under-reactor zone and inside the technological channels and cells of the reactor.

2. Object for robots implementation

Two working zones are considered: the central (reactor) hall and reactor itself. The central hall situated above the reactor is 24 m wide, 54 m long and 33 m in height.

In fact the floor of the central hall is an object of maintenance. The most probable task is removing of fuel assembly tablets parts, which can fall down to the central hall floor during process of transportation to the storage pool. Radiation situation in this case depends upon quantity of the lost fuel and distance from the manipulator.

There are 2 main difficulties in reactor technological channel inspection and maintenance: strictly limited geometrical parameters of the channel and very high level of radioactivity. A technological RBMK channel is a vertical tube of complex geometry made of Zr and Nb alloy with minimum internal diameter - 80 mm and total length - 18 m. Active reactor zone length - 7m. Technological channels are surrounded with graphite laying which consists of graphite blocks (rectangular, 250x250 mm with a hole of 114 mm in diameter). A fuel assembly is placed hermetically inside the channel. Radioactivity inside graphite blocks and channels of stopped reactor comprises alfa, beta and gamma-rays. At Leningradsky power plant reactor channels gamma-rays level is about 1800-2000 roentgen per hour.

3. Proposed solutions

Channel type reactor maintenance practice determined developing of 3 independent teleoperated systems for inspection and remote handling:

1. Teleoperated / automatic robot for the central hall providing a wide range of technological operations under unpredictable environmental conditions.

2. Remotely controlled inspection and fuel assembly pieces removal system for the channel with cross section diameter of 80 mm and length of 18 m.

3. Teleoperated system for handling and removal of fuel assembly and graphite blocks pieces from the channel with rectangular cross section (250x250 mm).

Teleoperated systems should include several subsystems such as: TV viewing system, lighting system, manipulator, geometric parameters measuring system, gamma-rays level measuring system, end effector fixation system, azimuth measuring system.

4. Design implementation

Bellow follows a brief description of the above mentioned teleoperated systems.

Teleoperated / automatic robot

Teleoperated / automatic robot consists of remote master-slave manipulator; stereo-TV system; mono-TV system (3 pieces); transport device, special set of changeable tools, control and operation equipment.

Manipulator consists of articulated slave arm with joint drive units containing electric motors, harmonic gears, speed, position and advanced torque transducers (the slave is made of titanic alloys and stainless steel), replica master arm, equipped with position transducers and brushless DC motors, control console containing standard electronics housing cages, operator console, cable set, set of tools. The slave drives contains 5 bilateral drive systems with brushless DC motors, rectifiers and transistor invertors. Control system of manipulator provides teleoperated and automatic work regimes.

Main technical data:

max. load capacity, kg	25
degrees of freedom, number	5
gripper squeezing force range, N	50-600
max. distance between master and slave, m	100
total consuming power, kw	2.5
mass, kg:	
slave arm	90
master arm	70

Main design principles: bilateral servodrives with automatic force control and advanced force reflection, modular drive units (M-54 design principle), remotely changeable tools, ability to be placed at any of vehicles.

Remotely controlled channel inspection system

Main technical data:

TV camera rotation speed, deg/s	16
TV camera rotation angle, deg	360
mirror rotation angle, deg	45
mirror movement control	incremental
gripper linear movement range, mm	0 - 49
gripper load capacity, kg	0.09
max. distance between control console and manipulative system, m	50
gripper squeezing speed, 1/s	1
lifter max load capacity, kg	22
manipulative system mass, kg	15
lifter position accuracy, mm	10
lifting speed, mm/s	11 and 21

This teleoperated system contains a mobile module and a remote operator control console. The mobile module provides working operations inside the reactor channels and consists of a manipulative system and a tower with an automatic lock (for connecting to the central hall heavy duty crane), a lifter with a cable drum and a mechanism for accurate manipulative system positioning above a channel.

The manipulative system is designed in the form of a cylinder with cross section diameter of 49 mm with built-in:

- electromechanical gripper;
- rolling mirror;
- TV camera with an objective, lighting system and image processing equipment;
- gripper drive;
- TV camera rotation drive;
- azimuth movement drive;
- channel geometric parameters measuring system and manipulator fixation system;
- electrical connector.

The gripper situated at the bottom side of the manipulative system provides small objects removal out of the channel. The gripper comprises spring loaded tongs activated by an electric drive. (Squeezing force - 0.9 kg; maximum load capacity - 90 g).

Strict geometrical requirements made the designers solve a very complicated problem of all the parts of the system mounting consequently inside the narrow steel tube body. For example the system TV camera should provide both side and axial viewing modes. Therefore the inclined mirror should have 2 fixed positions. For this a special "mirror on/off" mechanism was developed. Its main idea is to implement the same motor for activating the gripper and rolling the mirror. This motor activates the screw which makes a nut with a cam slot on the surface move along the screw. While the mirror finger is in the vertical part of the slot the mirror remains in the same position. But when passing the sloping part of the slot the finger makes the mirror move opening the axial view for the camera. Moving the nut farther with the mirror finger sliding along the second vertical part of the slot the motor closes the gripper without changing the mirror position. Moving the nut backwards the motor opens the gripper and then can change the mirror position returning to side viewing mode.

Such design solution provides a considerable system dimensions reduction.

Another peculiar feature of this manipulative system is a combined mechanism for a channel diameter measuring and the system fixation inside the channel.

The mechanism comprises 3 metal (3,969 mm in diameter) balls built into the system body. The balls can partly move out of the body until they meet the channel walls and fix the device inside the channel. The rotating ring pushing the balls outside is connected to the motor activating the mechanism and to the position transducer providing accurate (+/- 0,001 mm) displacement and therefore channel diameter measurement.

Teleoperated manipulative system for channel graphite laying repair

This system should provide following technical tasks:

- internal graphite block viewing inspection;
- geometrical parameters measurement;
- sampling;
- channel, fuel assemblies and block parts removal;
- inside-cell and cell-to-cell blocks rearrangements.

The system should comprise:

- teleoperated manipulator with 200N load capacity;
- TV viewing system;
- measuring system;
- temperature sensors;
- container for small objects;
- grinding machine;
- changeable grippers.

The system working zone cross section varies from a circle of 114 mm in diameter to a square of 250x250 mm.

The system is currently under development.

5. References

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