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«Testing Procedures of some Construction Rigidity Characteristics for the Irradiated FAs in the Hot Cells»

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ABSTRACT

During operation of the VVER reactor blocks the bowings of complicated form can appear. Their value is determined by a number of factors that can result in failure at work of the reactor control protection system.

In particular, the FA bowing can appear due to the increased axial load associated with the spring block operation. One more factor promoted the decrease of the FA construction rigidity is deterioration of the fixing conditions for FEs and guiding channels in the spacer grid cells. It is intensified after fuel burnup increase.

That's why one of the principal parameters necessary for creation and verification of the thermo-mechanical model of the FA and core is the bowing rigidity with which the FA constriction stability is associated.

The report presents the descriptions of the techniques and equipment which are used during examination of some FA construction rigidity characteristics in the RIAR hot cells.

In particular, the following is presented in the report:
- technique for determination of the FA form change;
- facility for FA bowing measurement at the cross load;
- methods for determination of the gaps between FEs and spacer grid cells;
- methods and devices for examination of the spring block characteristics.

The report presents the technical specifications of the facilities and methodical providing.

INTRODUCTION

At the increase of the VVER fuel burnup and compaign duration FA bowings can occur, that can affect safe VVER-1000 reactor operation.

The possible reason for the FA bowings can lie in the increased axial load which is basically determined by the work of the spring block and in decrease of FA bowing stiffness due to easing of the force in the pairs of «fuel rod-grid cell» and «guiding channel-grid cell».

Therefore to create and verificate thermomechanical model of the fuel assembly it is necessary to reveal factors which determine FA geometrical stability and to investigate their influence on the FA bowing stiffness change.

The present report considers the descriptions of techniques and equipment applied during the examination of some construction rigidity characteristics for VVER-1000 FAs in the RIAR hot cells.

1. VVER-1000 FA CONSTRUCTION.

A serial VVER-1000 FA consists of a top nozzle, bottom nozzle, 18 guiding channels, central pipe and 15 spacer grids (fig.1). The bottom plugs of the guiding channels and central pipe are fixed in a bottom spacer grid of the FA by welding. In the FA top nozzle the guiding channels are welded on the end faces and the central pipe can move in the axial direction. Thus axial load is distributed among
18 guiding channels.

Spacer grids from stainless steel are fixed in the slot of the central pipe in equal intervals (255mm). A beam of 312 fuel elements, 18 guiding channels and central pipe is fastened by these 15 spacer grids. Fuel elements are fixed in the bottom spacer grid of the FA through the holes in the bottom plugs.

The spring block located in the top nozzle provides FA axial compression in the reactor core.

2. EXAMINATION METODOLOGY OF THE REASONS FOR FA FORM CHANGE.

Sequence for the examination of the VVER-1000 FA construction rigidity lies in the following (fig.2). At the first stage measurements of the FA geometrical dimensions are carried out. They give the basis for determination of the FA form change during operation (shape of the FA axis and bowing).

After FA form change being determined, FA bowing values are measured at the cross loading. The parameters describing bowing stiffness are determined and the shape of the FA axis are restored at loading being applied and after it.

To estimate axial load acting on FA the spring block is examined. The basic requirement to the spring block is axial moving of the course without rubbing and jamming, as well as keeping elastic characteristics during the whole period of operation within design limits.

According to these requirements a course gap of the spring block is measured and, after the FA top nozzle being cut off, elastic characteristics of the spring block as a whole and separate springs are examined.

While fuel elements and guiding channels being taken out from the fuel assembly the force of pulling off and the force of taking them out from the FA skeleton are measured. After fuel elements and guiding tubes being taken out, their length and diameter are measured.

After spacer grids being taken out from the fuel elements and guiding channels, the inner sizes of the spacer grid cells are measured and the limits of the elastic movements of the cell walls are determined. According to the measured diameters of the fuel elements and guiding channels and inner sizes of spacer grid cell sizes, the values of gaps between them are calculated. Based on the efforts of taking FEs and guiding channels out, limit of the elastic movements of the cell walls and on cell-FE gap size, force in pairs of «fuel rod-grid cell» and «guiding channel-grid cell» is estimated.

Thus, based on the results of the examination the estimations of the axial load on the fuel assembly, the estimations of force in the pairs of «fuel rod-grid cell» and «guiding channel-grid cell» are obtained and parameter values are determined which describe FE bowing stiffness. It helps to analyze the reasons for FA form change.

3. TECHNIQUE AND EQUIPMENT

Measurement of FA geometrical dimensions is carried out on a measuring stand (fig.3). The stand consists of a support stand fixed on the base in the hot cell. A measuring carriage with sensors of linear voltage displacement transformers (LVDT) moves on guides along the mount. It records changes in distance between the carriage and FA side, accuracy is within ±0.02mm. The measurements are carried out on three side couples and they are initial data for calculation of the FA cross size, twist and reconstruction of the FA axis shape.

Fig.4 presents the results of measurement processing of the FA geometrical parameters which characterize FA form change.

To determine FA bowing stiffness by experiment a facility was developed which allows to measure the FA bowing value at cross load of the assembly (fig.5). The facility consists of three principal parts - loading system, units of FA fixture and FA bowing measurement systems.

The facility allows to carry out a FA bowing by applying the load perpendicularly to the sides at a level of spacer grid 8 and spacer grid 12. The load is transferred from the winch through the system of rollers to the loading ring, which closely spans the spacer grid. The design of the ring

excludes formation of the rotating moment in a horizontal plane. The accuracy of determination of the load on the ring does not exceed 1.0kgs at the load change from 10 up to 250kgs.

FA bowing is measured by TV-camera. When the camera is moving along FA the bowing value is measured at different height levels. The bowing measurement accuracy does not exceed 0.5mm.

At the FA bowing test a load is applied step by steps with unloading of 10-15kgs after each step.

For every height mark, where measurements were carried out, dependences of bowing value and residual bowing on the applied force (fig.6) are made. Based on the points obtained by experiment trajectories of the FA axis are restored at loading and after unloading. Fig.7 presents the example of the reconstruction shape of the FA axis at the load of spacer grid8 in the direction of two opposite sides.

The tests of the spring block and their separate springs are carried out in dynamic mode on the typical machine for mechanical tests at room temperature. Based on the obtained diagrams of spring compression of the spring block the following is determined: irradiated spring rigidity factor, relaxation value, change in spring block axial effort.

For the outer diameter measurement of fuel elements and guiding channels a contact profilometer with a converter of LVDT is used. The measurements are carried out in two mutually perpendicular planes with a step of 2mm. A diameter measurement accuracy is 0.012mm. Based on the measurement results the estimation of the average diameter is carried out.

The spacer grid cell sizes are measured by caliber with the cylindrical step diameter from 8.8 up to 9.2mm with a step of 0.01mm. The cell diameter is determined as an average value between diameters of two nearby caliber sections, which goes through the cell and doesn't go.

Elastic characteristics of the spacer grid cells are examined by means of device consisting of the conical rod which moves the cell walls apart at the given distance and a device for cell dimension measurement after taking the conical rod out of it. By means of these devices the maximal value of the elastic movements of the cell walls is measured.

By the described techniques and facilities a few VVER-1000 FAs were examined. Thus, methodical and technological equipment of RIAR hot cells allows to carry out complex tests of fuel assemblies and their elements to examine the FA construction rigidity characteristics.
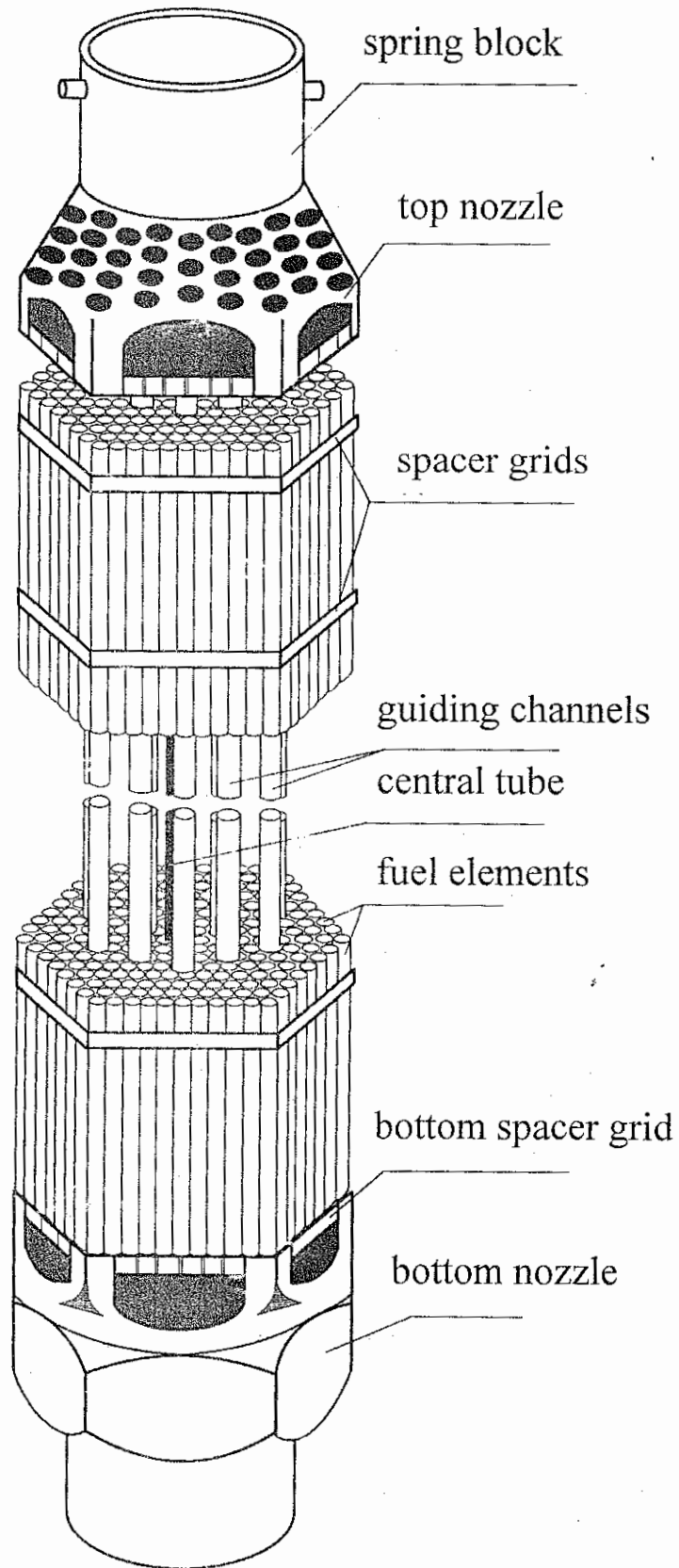
spring block

top nozzle

spacer grids

guiding channels

central tube

fuel elements

bottom spacer grid

bottom nozzle

Fig.1. VVER-1000 Fuel Assembly (Scheme)

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┌─────────────────────┐          ┌─────────────────────┐
│    Measurement      │─────────▶│    Determination    │
│ of FA geometrical   │          │  of FA form change  │
│    dimensions       │          │  during operation   │
└─────────────────────┘          └─────────────────────┘
          │                                 │
          ▼                                 ▼
┌─────────────────────┐          ┌─────────────────────┐
│    Measurements     │─────────▶│    Reconstruction   │
│ of FA bowings during│          │  of FA axis shape   │
│    cross loading    │          │ during cross loading│
└─────────────────────┘          └─────────────────────┘
          │         │                       │
          ▼         │                       ▼
┌─────────────────────┐          ┌─────────────────────┐
│    Measurement      │          │    Determination    │
│ of gap of spring    │          │ of parameter values │
│    block course     │          │  describing bowing  │
└─────────────────────┘          │      stiffness      │
          │                      └─────────────────────┘
          ▼
┌─────────────────────┐
│    Examination      │
│  of spring block    │
└─────────────────────┘

┌─────────────────────┐          ┌─────────────────────┐
│ Measurements force  │─────────▶│     Estimation      │
│  of FEs withdrawn   │          │  forces in a pair of│
│ from the skeleton FA│          │ «fuel rod-grid cell»│
└─────────────────────┘          └─────────────────────┘
┌─────────────────────┐                     ▲
│    Measurement      │          ┌─────────────────────┐
│ of diameter for FEs │─────────▶│    Determination    │
│ and guiding channels│          │  of gap between FEs │
└─────────────────────┘          │  and spacer grid    │
┌─────────────────────┐          │       cells         │
│    Measurement      │─────────▶└─────────────────────┘
│ of spaser grid cells│
│       size          │
└─────────────────────┘
          │
          ▼
┌─────────────────────┐
│   Determination of  │
│ elastic character-  │
│ istics of spacer    │
│    grid cells       │
└─────────────────────┘

┌─────────────────────────────────────────────────────────┐
│        Analysis of the reasons for FA form change        │
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┌─────────────────────┐
│ Estimation of axial │
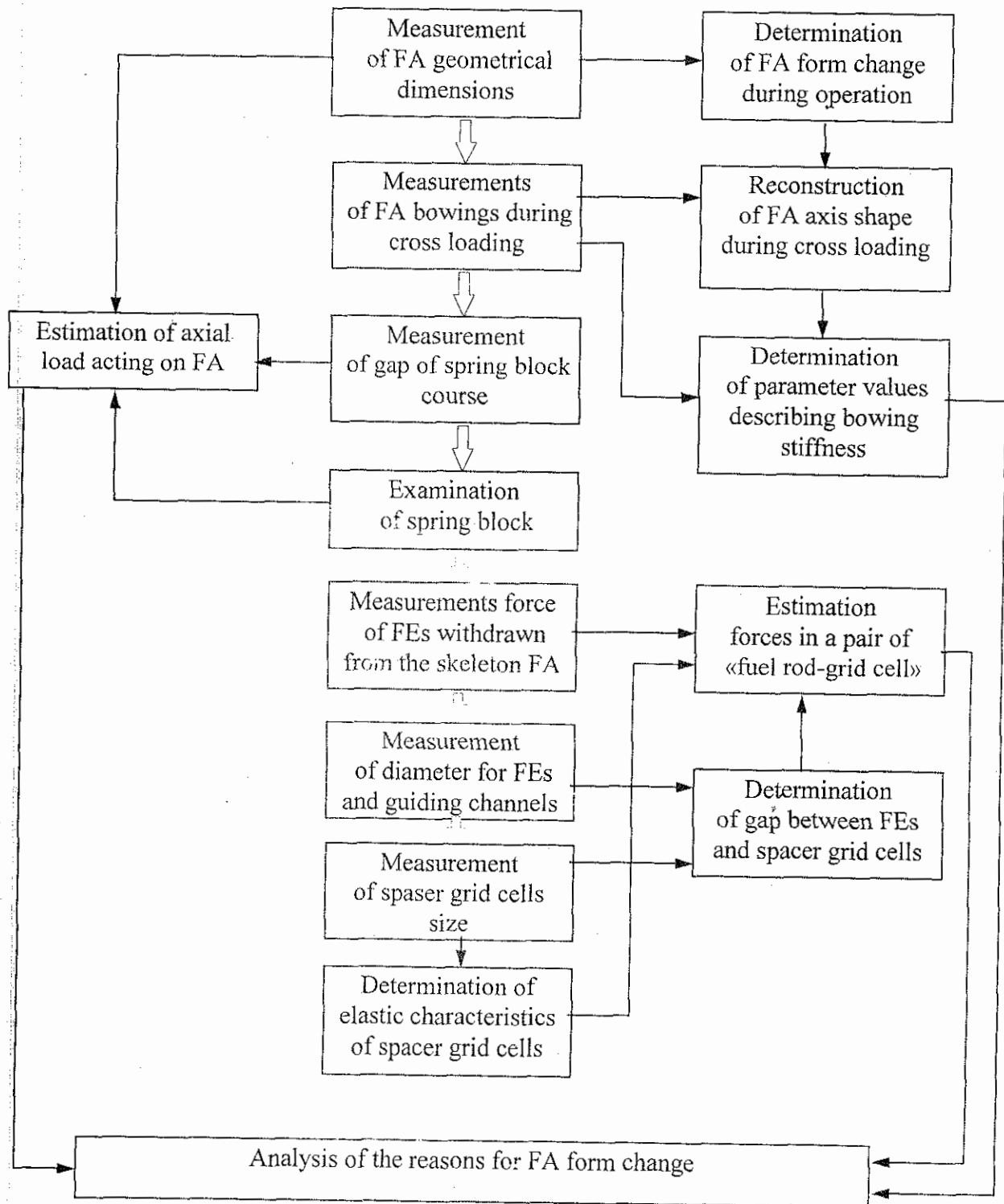│ load acting on FA   │
└─────────────────────┘

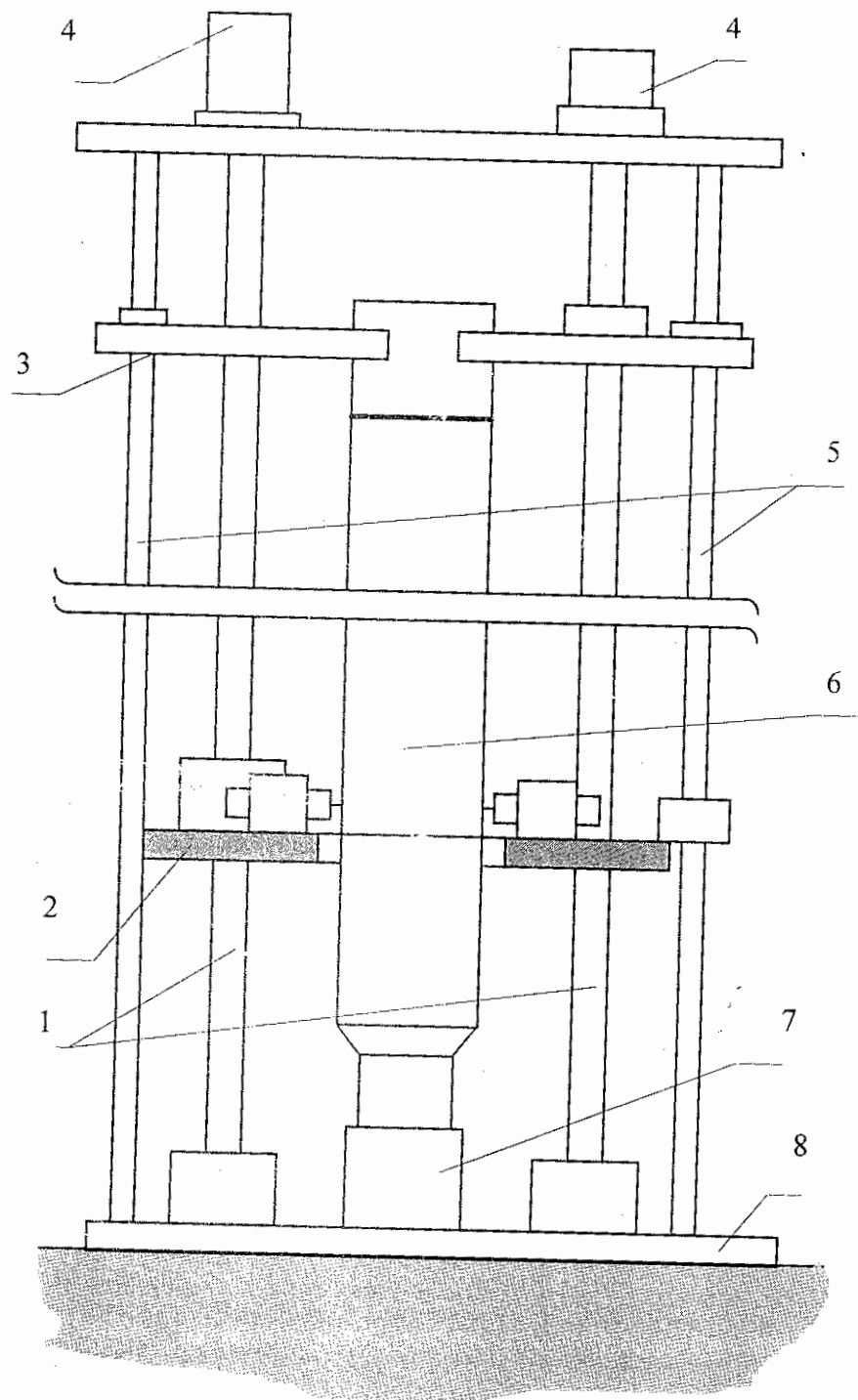Fig.2. The diagram of the analysis of the reasons for FA form change

Fig.3. Stand for measurement of FA geometrical dimensions:

1 - moving screws; 2 - measuring carriage; 3 - top (tightening) carriage; 4 - step-by-step engines;
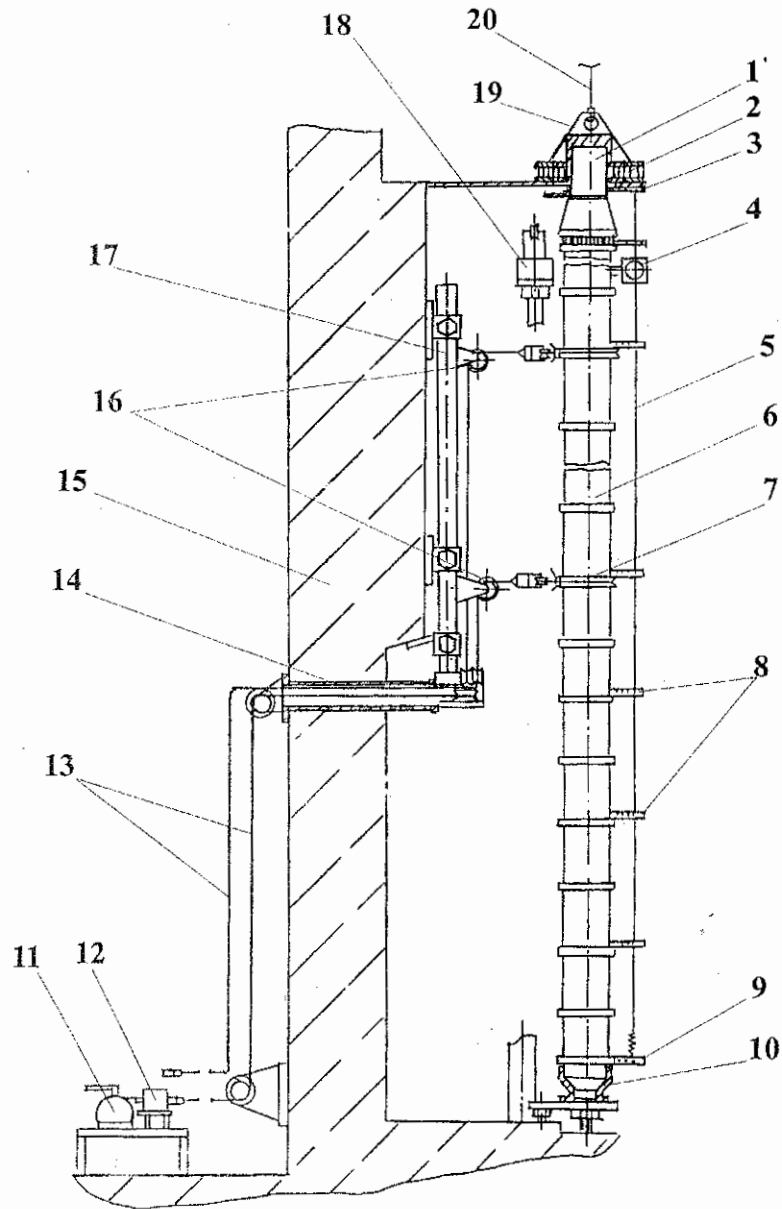5 - leading tubes; 6 - measured FA; 7 - step bearing; 8 - bottom plate.

Fig. 5. Test facility of FA bowing.

1 - FA top nozzle; 2 - FA top nozzle fixture unit; 3,9 - string fixture units; 4 - TV-camera; 5 - string; 6 - FA; 7 - ring; 8 - measuring ruler; 10 - FA tailpiece fixture unit; 11 - winch; 12 - dynamometer; 13 - cable; 14 - horizontal drifting; 15 - hot cell wall; 16 - rollers; 17 - vertical support; 18 - TV-camera leading tube; 19 - capture; 20 - elevating crane cable.
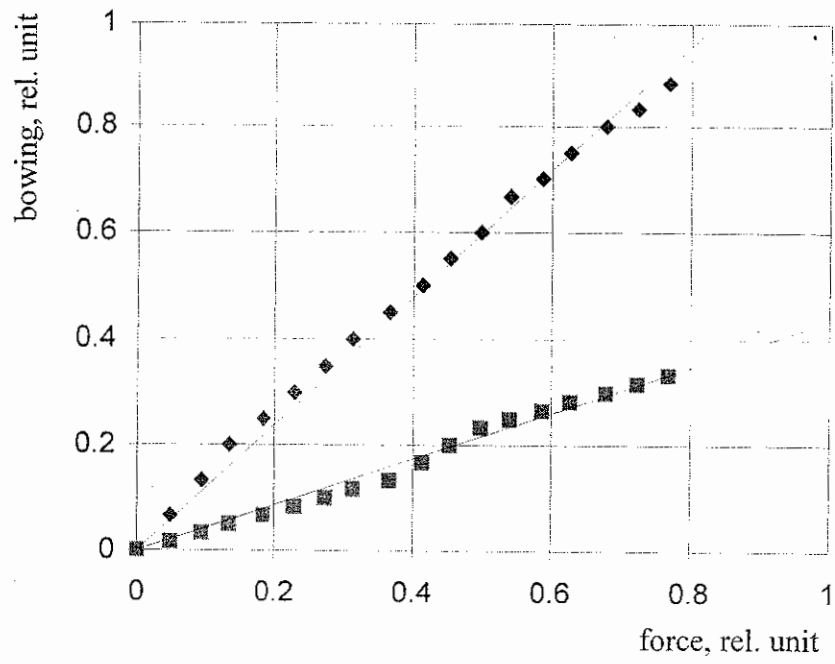
Fig. 6. Dependence of FA bowing value and residual bowing on the applied force:
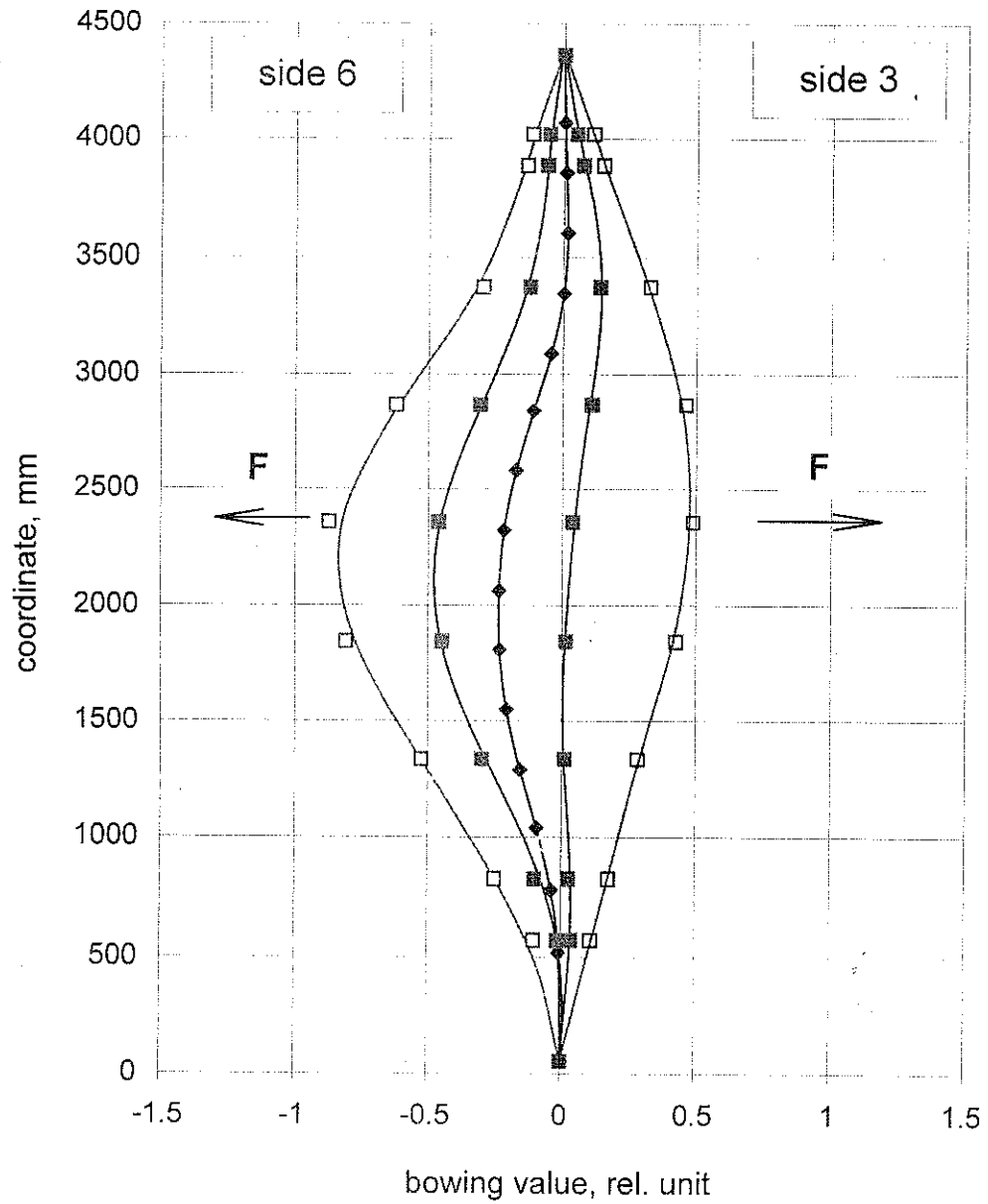
♦ FA bowing at loading

▩ residual FA bowing after loading

Fig. 7. FA axis shaps:

☐ -   bowing shape at louding;
▩ -   residual bowing shape after louding;
♦ -   initial FA bowing shape.