Calculation and Comparative Measurement of a Manipulator Boom

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INTRODUCTION

A manipulator system is fabricated for use in a fusion reactor /1/, /2/. The system allows to take in any arbitrary position in a plane (fig. 1). It consists of seven linked arms. During resting position, the manipulator boom is folded together in an antechamber. For the working position, the individual links are moved out through the opening to operate in a ring-shaped vacuum vessel.

The stress analysis of the boom follows three steps:

- Calculation of the global forces with a beam model dependent on the different working positions of the boom.
- Calculation of the local stresses in the jointed arms with Finite-Element-Models for the worst load combination.
- Comparison of the calculations with strain gauge measurements.

MANIPULATOR BOOM

The manipulator boom consists of a first arm of about 4 m length which is moveable only in axial direction in the antechamber and 6 moveable arms of 1.65 m average length. The global static system is a cantilever beam which is clamped to the first arm by use of 4 driving rollers. The boom is stressed by bending and torsional loads during movement and at the working position in the ring-shaped reactor. To withstand these stresses, the individual arms are designed in a boxed-type construction. Each of these boxes ends in a pair of joint plates which are connected to the adjacent arms by vertical bolts. These bolts allow rotation of the arms in the horizontal plane. The back pair of the joint plates is narrowed down, so that they fit into the joint plates of the following arm (fig. 2).

The movements of the manipulator boom are controlled by a electro-mechanical system of link rods which are connected to the bolts in the hinges. All parts of the control system are arranged within the arms, so that openings in the bulk heads of the boxes are necessary for the link rods.

CALCULATIONS

As a result of the calculations in the first step, fig. 3 shows the torsional and bending moments in the front hinge of arm II, referred to the different working positions. It is obvious that in general the maximum bending moment does not coincide with the maximum torsional moment. The maximum stresses in arm II are caused by the torsional moment.

In the second calculation step, the finite element method is used to analyse each individual arm with uncoupled, singular models (fig. 4). In these models each arm is assumed to be clamped at its back joint plates and loaded at its front joint plates in accordance with the global beam model.

Fig. 5 shows the deformations of the bulk heads of arm II in a strongly increased manner. The maximum stresses are in the corner areas of the bulk heads and at the openings of the side plates. The global level of stresses in the box is relatively low.

MEASUREMENTS

Measurements were conducted after fabrication of the boom to verify the precalculations. Only the first two arms were investigated as first step. A long tube was fixed at arm II to obtain the maximum load level of the working condition (fig. 6). The load on the tip of the tube as well as the position of the two arms and the tube were chosen in a way to obtain the desired load level at both arms. It was paid attention to avoid overstressing in the first arm.

The strain gauges were fixed in the mostly stressed areas in accordance with the calculations.

Because good agreement was achieved between calculation and measurement, all other arms were designed in a similar way.

During testing of the control system for the arms, further measurements were conducted under realistic load positions.

COMPARISON OF CALCULATION AND MEASUREMENT

Fig. 7 shows the maximum reference stresses in the bulk heads of arm II under the main working loads for the different working positions. The stresses reached their maximum during spreading of the boom within the antechamber. Furthermore, the different stresses for right-hand and left-hand movement within the reactor are shown. The course of the reference stresses with respect to the load positions coincides with the course of the torsional moments in fig. 3.

The comparison with the calculation results for the ruling load positions reveals that the calculations in general overestimates the stresses. Altogether, the measured stresses are less than the allowed stresses. That fact is even more true, because the tests were performed with maximum loads. It can be assumed that generally the actual loads in practice are lower.

The manipulator system has fully satisfied its functions during all further investigations so far.

REFERENCES

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- /2/ Loesser, G.D., Heitzenroeder, P., Böhme, G., Selig, M. (1987), THE TFTR MAINTENANCE MANIPULATOR. Proc. 35th Conf. on Remote Systems Technology, Los Angeles, pp. 161 ÷ 165.

Fig. 1 Overview

Fig. 2 Moveable Arm I

Fig. 3 Moments in the Front of Arm II

Fig. 4 Finite Element Model Arm II

Fig. 6 Measurement Devices

Fig. 5 Deformations of the Bulk Heads of Arm II

Fig. 7 Stresses in Bulk Heads of Arm II under Working Position