Layout of the manipulator-arm (boom) for the TFTR fusion reactor (Princeton, USA) under UHV-conditions

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1 Introduction

This presentation will show the main criteria for the layout of the manipulator - arm and the antechamber - vessel of the TFTR - FUSION - REACTOR at Princeton University , PLASMA PHYSICS LABORATORY (USA).

The design - conditions are listed below :

- temperature T = 150 C (within the torus
- pressure P = 10E-8 mbar and ante-chamber)
- life - load F = 500 kg (at the tip of the boom)
- max. velocity of MM - arm v = 25 mm/s
- earthquake - conditions (MPE)

The mechanical model of the boom will be represented by beam-elements with external concentrated and distributed loads.
The interaction between deadweight and stiffness will be discussed and the static deflection of the complete construction will be analysed in detail (fig. 3 - 5).

Different materials will be discussed in order to show the criteria for the chosen austenitic material X2CrNiMoN1813 (1.4429) for most parts of the construction.

The influences of earthquake - accelerations to the design of the complete configuration will be analysed.
The dynamic interaction between the antechamber - vessel and the carriage of the boom will be shown (two - mass model) . Different ways of analytical solutions will be presented.

2 MECHANICAL MODEL OF THE MANIPULATOR - BOOM

The boom will be represented by a beam model with different stiffnesses and external concentrated and distributed loads.

These loads produce dependend on the different working positions within the torus bending- and torsional moments within the configuration .

The calculation system for the boom is shown in fig. 2.
The main criteria for layout will be the limitation of the max. deflection f_{max} at the tip of the boom.

The variation of the vertical deformation is shown in fig. 3 - 5 for different positions during enfolding within the antechamber (fig. 5) and for different working-positions within the torus (fig. 3/4).

$$(1) \quad f_{Mb} = \frac{M_B \times \bar{M}_B}{E \times I_{x-x}} \times dx \qquad \text{(due to bending moments)}$$

$$(2) \quad f_{Mt} = \frac{M_T \times \bar{M}_T}{E \times I_t} \times dx \qquad \text{(due to torsional moments)}$$

$$(3) \quad f_{max} = f_{Mb} + f_{Mt}$$

3 STRESSES AND BUCKLING - BEHAVIOUR

The dimensions of the cross - sections of the beams were designed in respect to the necessary space for the built-in parts such as spindle , motor etc. and the dimension of the opening of the TFTR - Torus .

Additionally different materials have been discussed :

Material	Young's modulus [N/mm**2]	Weight [kg/dm**3]	Ult. stress [N/mm**2]
Titanic	1.05E05	4.54	700
Alumen	6.75E04	2.70	400
X2CrNiMoN1813	2.10E05	7.80	300

The advantage of smaller weights for Ti and Al will be balanced by the smaller values for the moduli of elasticity .

Furtheron difficulties during fabricating process will be exspected (machining and welding of the different plates).
This is why the austenitic material has been chosen (non magnetic !) .

The most critical parts during stress-calculation have been the transitions between the cross-section of beam-elements and the bearings of the links with the rollers.

The dimensions have been chosen in respect to stress-criteria (local stresses) and buckling - requirements.

Limiting criteria have been taken from the german technical rules , e.g. DIN 18.800 and DAST 012.

The safety factors for the different load-cases other than operating condition have been calculated in respect to the above mentioned regularity guides and to KTA 2201.4 for earthquake requirements (MPE).

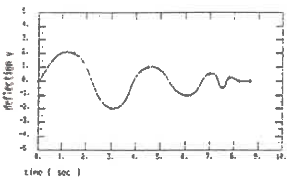
The special problems for fabricating the different parts in respect to the requirements under UHV - conditions had to be met .

4 Dynamic behaviour of the MM - Arm

4.1 Operating - conditions

The MM - Arm shows low frequency behaviour , i.e. the 1st fundamental eigenfrequency is about 2.5 Hz .

The dynamic deflection caused by a forced vibration will come down to the static deflection within a period of 5 - 8 sec (calculated by Time-History-Analysis).



(The variation of the static deflection is shown in fig. 3 - 5)

4.2 Earthquake conditions (MPE)

The complete plant has to be designed to sustain additional loadings from earthquake accelerations (MPE = OBE) .

The most important aspect in order to analyse the seismic behaviour of the plant is the dynamic interaction between the antechamber's configuration and the manipulator-unit (rails, carriage).

The system has been treated as a simplified coupled Two-Mass-Model . The construction of the antechamber had to be stiffened in order to achieve higher eigenfrequencies and to avoid amplifications of the dynamic vibrations .

5 Conclusion

The main problem during layout of a manipulator system like the TFTR - Boom has been the limitation of the vertical deflections due to dead-weight of the construction .

The design problem is rather a deformation problem and a problem of stability than a stress problem .

The way of optimizing the ratio between stiffness and deadweight is the most important part during the complete design - process .

Additional earthquake requirements need further investigations for a satisfying layout (horizontal forces, weak-axis of moment of inertia) .

The details of the construction (weldings , connections etc .) have to be designed in respect to UHV - requirements --> no holes and no fillet welds (outgasing - rate !) are allowed.

All weldings have to be designed as bevel-welds.

This manipulator system is designed for working in a plane system (two degrees of freedom) .

A manipulator system with the same operating capabilities in a three degree of freedom system needs larger cross sections for the different beam-elements than those of the discussed TFTR - BOOM .

6 Acknowledgement

This report has been written on the basis of information the author gathered during the coorperation with Kernforschungszentrum Karlsruhe (IT) and Princeton University (PPPL) for the TFTR - Manipulator - Boom - layout .

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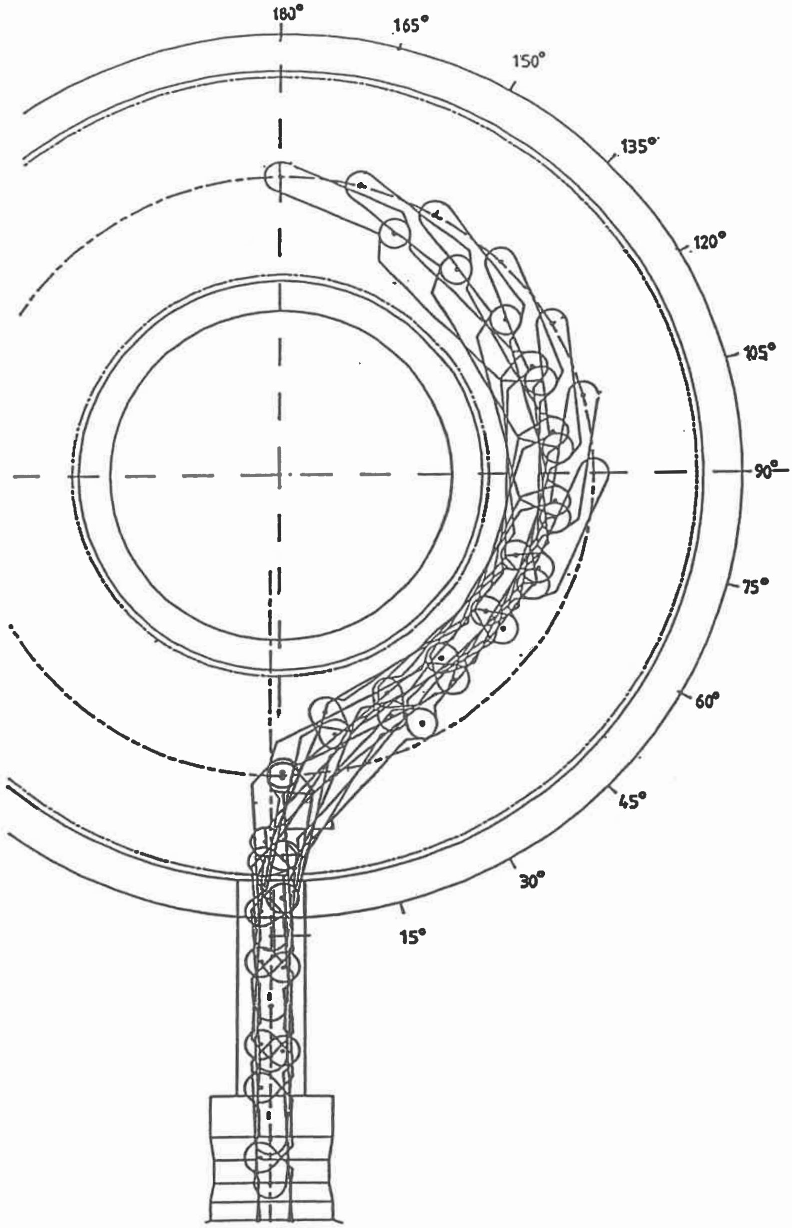

Figure 1. Different working positions within the torus.

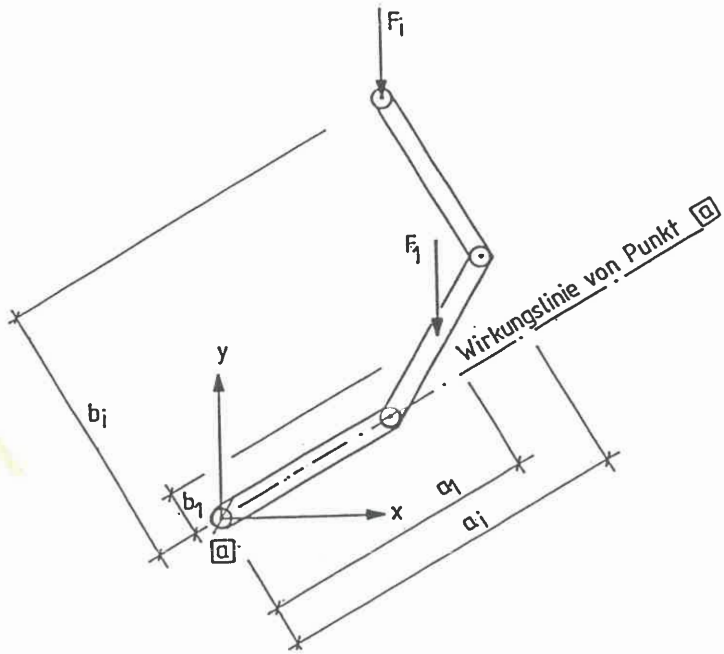

Figure 2. Static system

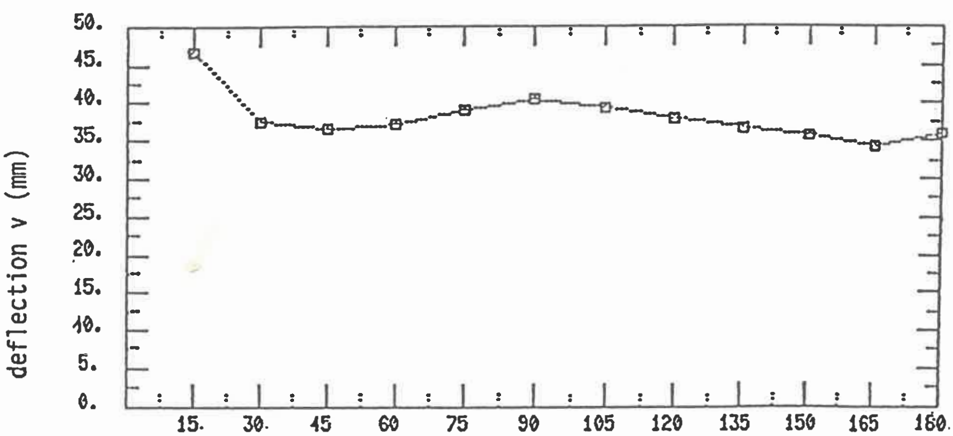

Figure 3. Working positions b15 - b180. Vertical deflections (node-no. 9) for different working positions (small radius).

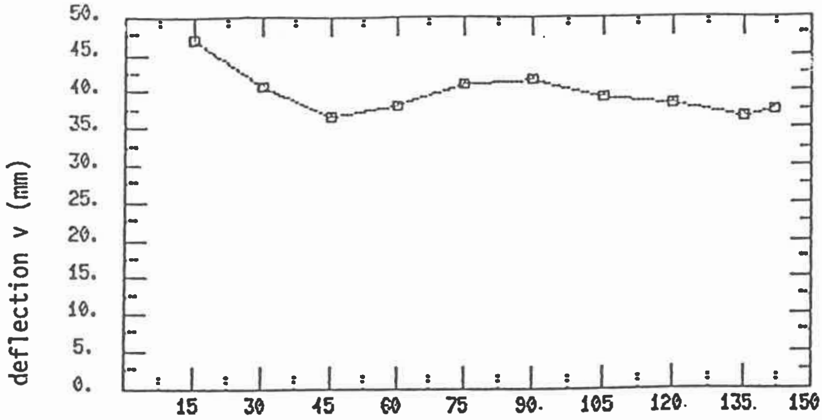

Figure 4. Working positions ba15 - ba142. Vertical deflections (node-no. 9) for different working positions (large radius).

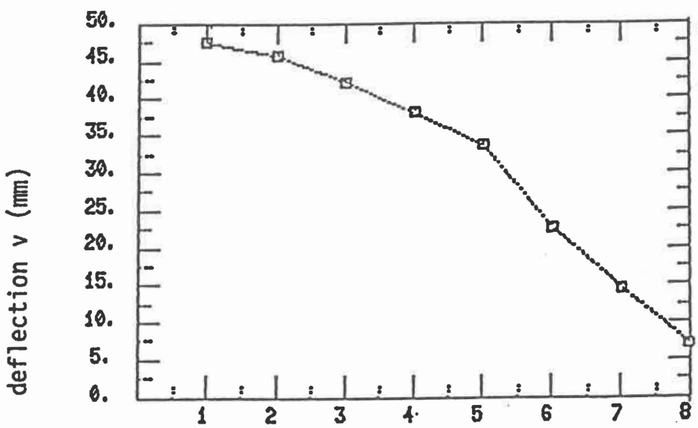

Figure 5. Positions y1 - y8. Vertical deflections (node-no. 9) during enfolding.