Vertical supports of the PV Wendelstein 7- X

M. Schrader[1)], T. Koppe[1)], A. Cardella[1)], B.Missal[1)], A. Capriccioli[2)], P. Friedrich[3)],

[1)] *Max-Planck-Institut für Plasmaphysik, EURATOM Association, Teilinstitut Greifswald, Wendelsteinstraße 1, D-17491 Greifswald, Germany*
[2)] *ENEA Frascati, Via Enrico Fermi, 45, 00044 Frascati (RM), Italy*
[3)] *Universität Rostock, FB Maschinenbau und Schiffstechnik, A.-Einsteinstr. 2, 18051 Rostock, Germany*

email: michael.schrader@ipp.mpg.de, phone: +49-3834-88-2718, fax: +49-3834-88-2709

Abstract

At the Max-Plank-Institute for plasma physics (IPP) in Greifswald, the stellerator Wendelstein 7-X (W7-X) is under construction. The toroidal plasma with a major diameter of 11 m is enclosed by a plasma vessel, whose geometrical shape closely follows the shape of the plasma-beam. The plasma vessel supporting system is divided into two separate subsystems, the horizontal support system and the vertical support system (VSS). The assignment of the horizontal support system is to centre and to adjust the plasma vessel during radial thermal expansion in the horizontal direction. The vertical support system is designed to resist the plasma vessel dead weight and other vertical loads coming from attached structures and to allow a vertical adjustment. This paper describes the design of the VSS and the testing conducted at the University of Rostock to validate the design.

Keywords: vertical support, plasma vessel, bearing, friction force, test procedure

1. Introduction

At the Max-Planck-Institute for plasma physics (IPP) in Greifswald, the stellerator Wendelstein 7 (W7-X), a superconducting helical advanced stellarator, is under construction.

The plasma-beam of the W7-X is enclosed by the plasma vessel (PV), which consists of five uniform modules, which have to be supported and adjusted vertically. Prior to the plasma start-up as well as during operation the PV may need heating. In this case, the diameter of the PV will extend by up to 20 mm. With respect to the magnet system the PV must remain centred; it should also be adjustable in horizontal direction. The PV supporting system has therefore been divided into two separate systems. The horizontal support system has been designed to centre the PV during radial thermal expansion and for adjustment in the horizontal position. The vertical support system has been designed to resist the vertical loads, to adjust the PV vertically and to allow horizontal movement of the PV. Figure 1 shows a cut through the cryostat. The possible movements of the plasma-vessel caused by thermal expansion are indicating in the drawing.

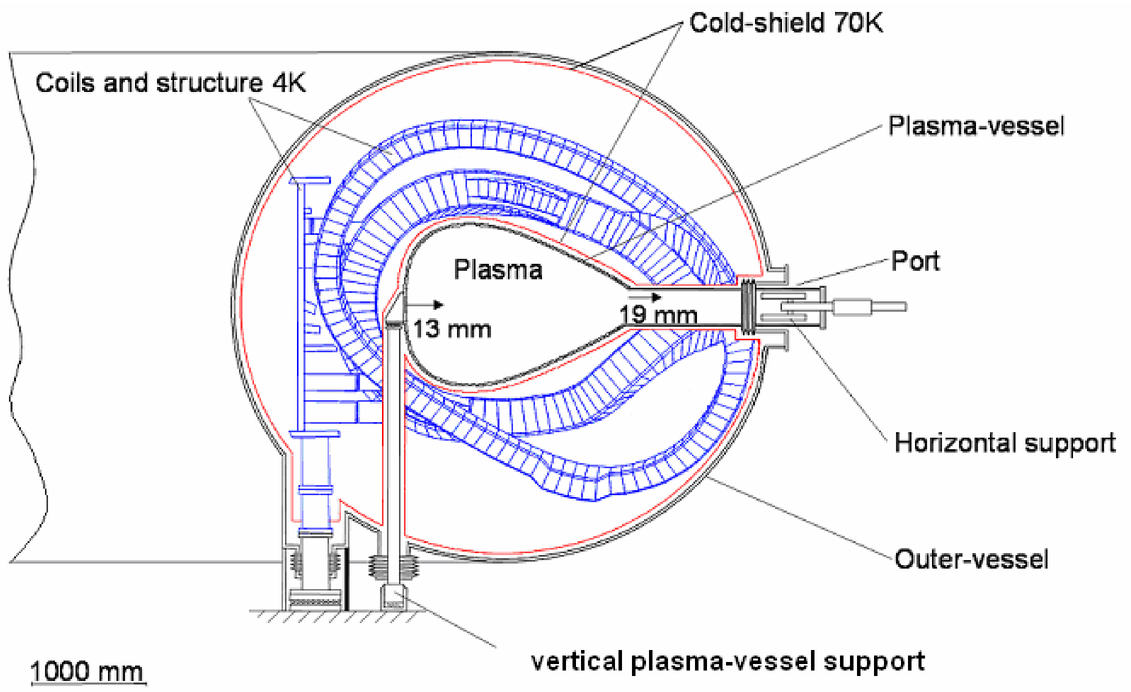

Fig. 1: Schematic view of main components of Wendelstein 7-X

2. Main functions and requirements of the vertical support system

The vertical PV support system (VSS) has to perform 3 different functions. It has to resist all the vertical loads caused by the dead weight from the PV, the ports and the in-vessel components, the vacuum loads, the spring forces of the port bellows and outer forces from components attached to the supply ports. Table 1 shows a list of these forces.

source of forces					Summary
mass loads				forces during operation	
plasma vessel 300 kN	ports (pro-rata) 300 kN	in-vessel components 300 kN	supply components 30 kN	vacuum force, spring forces from the bellows i.e. 370 kN	1300 kN

Tab. 1: Vertical forces from the main components of Wendelstein 7-X [1]

The whole plasma vessel is supported by 15 vertical supports. For safety reasons it is needed, that the total weight of 1300 kN can be distributed to only 10 supports. Therefore every support has to be able to carry a load up to 130 kN.

Secondly the ports have to resist lateral forces and allow movements caused by the thermal expansion.

Thirdly the VSS has to be able to adjust the vertical movement of the plasma vessel. This is implemented using hydraulic cylinders. The maximal allowed displacement in vertical direction is ± 10 mm. The system has to withstand 1000 horizontal movements in its life time caused by thermal expansion. The temperature range is from -50°C up to

+150°C. The maximum vertical and horizontal movements consist of the thermal expansion, the adjustable stroke and a safety factor. These maximum values are listed in Table 2.

vertical Movements	horizontal Movements		
± 10 mm	outer direction +31 mm	inner direction - 8 mm	cycles 1000

Tab. 2: Allowable movement of the plasma vessel of Wendelstein 7-X

3. Design description of the vertical support system

Each of the five uniform PV modules will be supported by three vertical supports each with different lengths. Two supports (AEX, AFF) are located on the inner side and the third (AEA) is situated at the outer side of the PV. See Figure 2. These supports are named according to ports nearby.

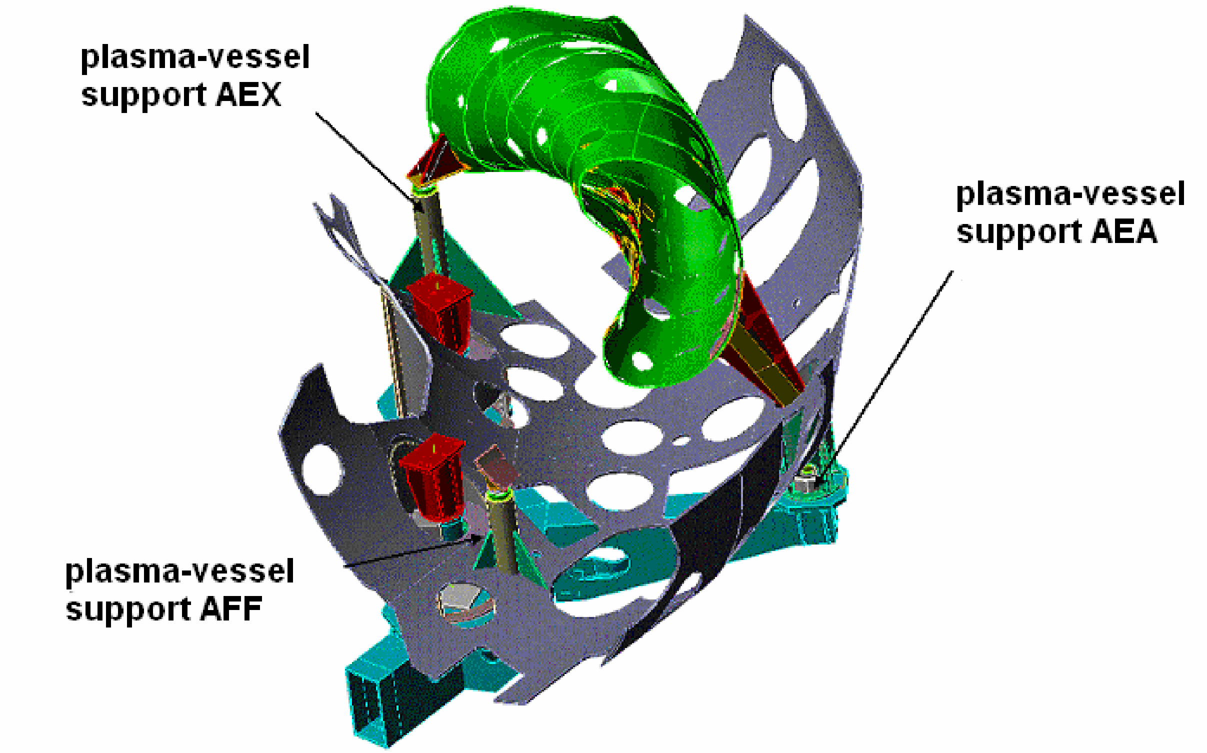

Fig. 2: Half module of plasma vessel with vertical support-devices in shell of outer vessel

High friction forces in the bearings in horizontal direction have to be avoided; therefore the PV support has been designed as a pendulum support [7]. This design consists of vertical tubes with spherical heads. The spherical bearing at the bottom is a fixed bearing, but the bearing at the top of the support-device is free to rotate around the fixed bearing. The pendulums can withstand all mentioned vertical loads but due to the nature of their design cause horizontal movement. To prevent a horizontal displacement of the PV, the horizontal support fixes the PV during operation. Additional, a further tube with a sliding plate which is attached at its upper end will be mounted. This second tube is only needed for the assembly of the plasma vessel. After the assembly, the pendulum will be lifted up by the hydraulic cylinder and the PV will be lifted from the sliding plate. Both of these situations are shown in Fig. 3.

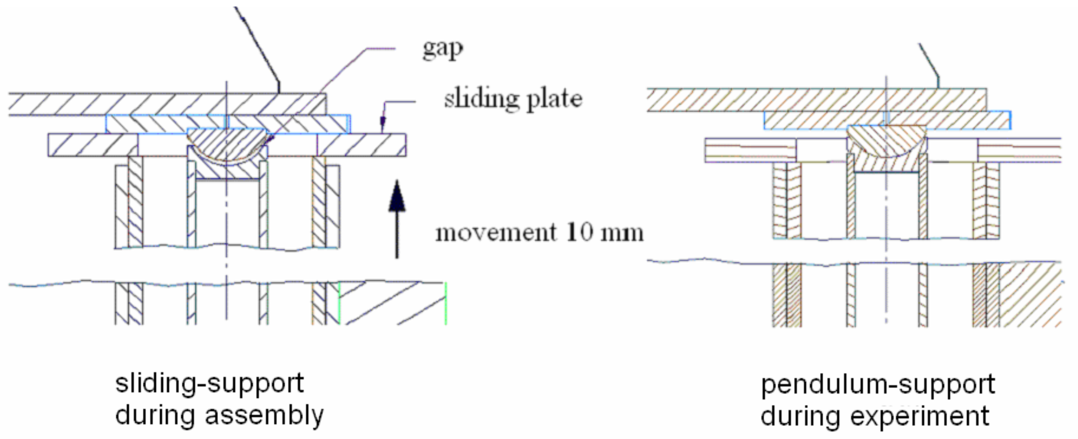

Fig. 3: Schematic view of the pendulum support during assembly and experiment [1]

3.1. Materials

All materials exposed to the nuclear radiance must be suitable for these conditions. The cobalt content had to be less than 500 ppm. To prevent an influence of the magnetic field, the relative permeability of the material has to be under 1,01 H/m. The steel used for the PVS has the material number 1.4429. The mechanical and technological qualities are tested before the application. The material combination of the cup and ball bearing has a special importance concerning the friction factor. After pre-tests a material combination of 1.4429 and lead bronze CC496K was selected for the spherical bearings [4, 2]. The lead bronze was selected because of the good dry running characteristics due to the fact bearing lubrication can not be guaranteed for the entire lifetime of the experiment because after assembling the upper bearing becomes unreachable. The lead bronze CC496 can also be used at low temperatures.

4. Test of the pendulum support system

4.1. Experimental destinations

The pendulum support system has been tested to verify the capability of its requirements and to find out the changes of the friction factor with an increasing number of load cycles. The PV should be able to expand or to be adjusted without any deformations of the PV through the effect of the friction forces. In order to prove that the pendulum support system has a low frictional resistance a series of experiments were developed, which were carried out at the University of Rostock. Due to the fact that the friction factor is dependent on lubrication in the vacuum, a vacuum compatible molybdenum disulphide was used. However, during the long time of the operation it is possible that the lubrication properties will decrease. Therefore the following tests have been carried out in lubricated and non-lubricated conditions. In the non-lubricated state, so-called slip-stick Effects could occur and also the influence of the pendulum length should be examined during these tests. For this reason, 3 pendulums with different length were produced and tested with the respective original dimensions. After the tests the data was examined in order to assess the rubbing surfaces and the employed materials.

4.2. Experimental setup

The stability of the experimental setup was ensured by a stable screwed frame. The design load of 130 kN was applied by a force controlled hydraulic cylinder (4 in Fig. 4). The force was constantly measured by a load cell (2). Due to the fact that the PV can shrink by 10 mm and extend by 20 mm during the different states of operation, a second hydraulic cylinder (3) had to simulate these conditions. This hydraulic cylinder is displacement controlled and the required forces for these movements were also measured by another load cell (1).

The rolling resistance of the roller bearing was determined in a pre-test [6]. The value was negligible. The influence of the exact geometry of the spherical bearing is very important concerning the Stick/Slip Effects. Therefore very tight tolerances and a defined roughness were used.

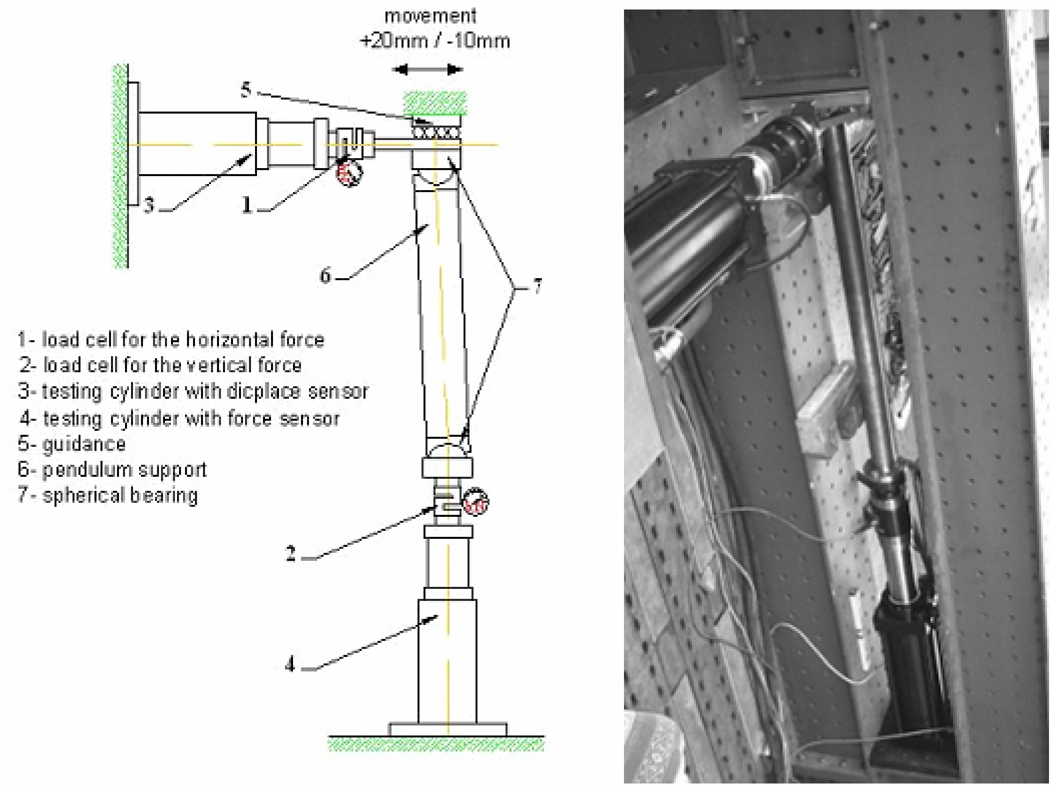

Fig. 4: Principle and original view of the experimental setup

4.3. Test procedure

Three pendulum supports with the material combination 2.0978/1.4301 and different length with 2 different loads in lubricated and non-lubricated conditions have been investigated in previous testing to prove the function of the pendulum support and to study the influence of the pendulum length. As expected the measured horizontal forces are higher with shorter pendulums and higher without lubrication. In this test the horizontal forces increased slowly up to the 10th cycle. A slip-stick Effect occurred during the 1000th cycle in the non-lubricated state. The effect started after approx. 100 cycles. The horizontal forces and the slip-stick effect increased in strength with the number of cycles.

For this reason, an additional set of tests was started with the new material combination CC496K/1.4429, the smallest pendulum and a modified bearing geometry. In this case the diameter of the bearing was reduced from 80 mm to 75 mm and the roughness was reduced to Ra = 0.2. The tolerance of form was reduced to 0.02.
Further more 1000 cycles with the shortest support were additionally performed in a lubricated and a non-lubricated state.
In the first part of the test procedure the pendulum support completed 10 cycles in a non-lubricated state with a load of 130 kN successfully. No slip-stick Effects occurred.
After this first part of the test only the upper bearing was lubricated. This condition was chosen because it is not possible to guarantee the lubrication for this bearing over the whole lifetime of the W7-X experiment. An advantage of this combination was the comparison of the bearings appearance in a lubricated and a non-lubricated state after 1000 load cycles. During this part of the experiment no slip-stick Effects occurred.
The plots of horizontal forces over displacements are shown in figure 5 and figure 6.
As expected the horizontal forces increases with the number of cycles.
The occurring horizontal forces and the resultant friction factor are given in Tab. 3.

	max. horizontal force [kN] (traction)	max. horizontal force [kN] (compression)	resultant average friction factor by 130 kN
130 kN, non lubricated, load cycle 1	3,6	-5,6	0,035
130 kN, non lubricated, load cycle 11	2,9	-4,8	0,029
130 kN, non lubricated, load cycle 1000	3,9	-6,01	0,038

Tab. 3: Horizontal forces with a load of 130 kN, pendulum length 621 mm [3]

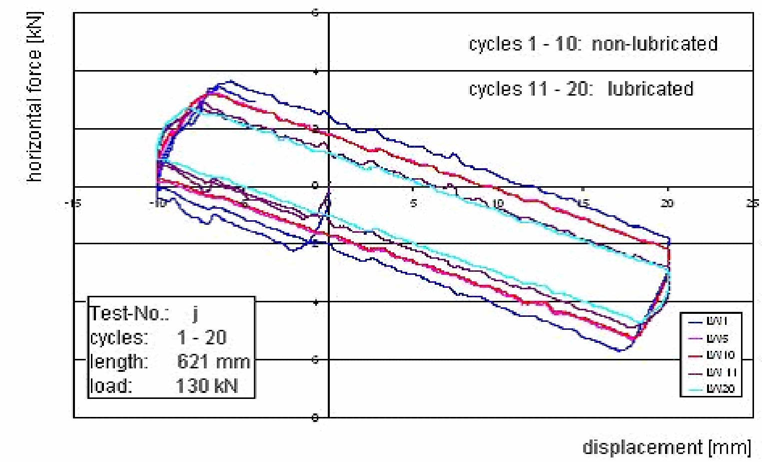

Fig. 5: Horizontal force- displacement- process with a load of 130 kN, cycles: 1 – 20 [5]

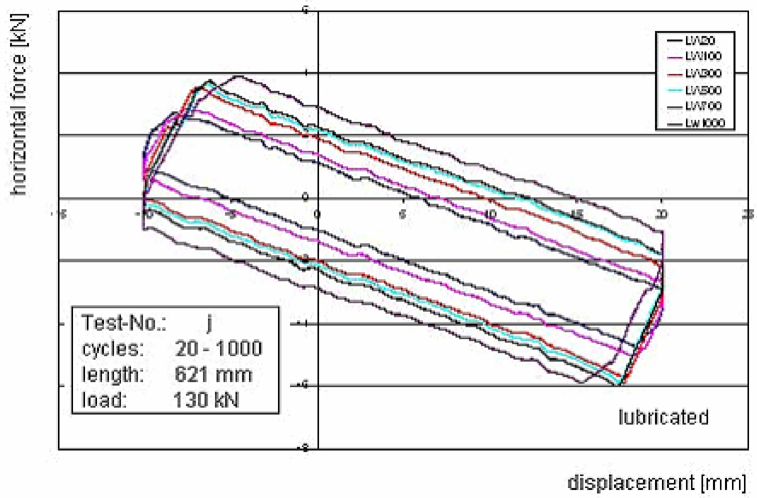

Fig. 6: Horizontal force- displacement- process with a load of 130 kN, cycles: 20 – 1000 [5]

5. Conclusions

The general usability of the pendulum support was proved with these experiments. The resulting friction factor was very small. This leads to smaller horizontal forces in the case that the PV should be displaced. Stick/Slip Effects could not be observed either in lubricated conditions or in non-lubricated conditions.
After 1000 load cycles there were no visible scratches on the lubricated bearing and at the non-lubricated bearing minor scratches were visible. Reason for this effect is the good dry running characteristics of the material CC496K.
This last test confirmed the use of the material combination of CC496K and 1.4429.
There are also some non-negligible special quality demands on geometry and surface of the sliding bearings like accuracy of sphericity and roughness.

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