

NURETH14-450

PRESSURE SURGE IN WENDELSTEIN 7-X EXPERIMENTAL STELLARATOR FACILITY

A. Kaliatka¹, E. Uspuras¹ and T. Kaliatka¹
¹ Lithuanian Energy Institute, Kaunas, Lithuania

Abstract

Fusion is the energy production technology, which could potentially solve problems with growing energy demand of population in the future. Wendelstein 7-X (W7-X) is an experimental stellarator facility currently being built in Greifswald, Germany, which shall demonstrate that in the future energy could be produced in such type of fusion reactors. Lithuanian energy institute (LEI) in the frames of European Fusion Development Agreement (EFDA) program is cooperating with Max Planck Institute for Plasma Physics (IPP, Germany) by performing safety analysis of fusion device W7-X. In this paper the consequences of potential water hammer effects were analysed only for the case, when the plasma vessel is operating in the “baking” mode. “Baking” is the mode of facility operation during which the vacuum vessel structures are heated up to 150 C in order to release absorbed gases from the surfaces and to pump them out of the plasma vessel before plasma operation. For the analysis the thermal-hydraulic model of target (torus) modules cooling / heating systems in W7-X facility was developed using RELAP5/Mod3.3 code. The performed analyses showed that the pressure pulsations in pipelines of cooling / heating systems are possible only in case of very fast closure of automatic valves in torus modules inlets and check valves in torus modules outlets. The maximum dynamic loading to cooling / heating systems pipelines due to such valves activations is in the range 0.12 – 0.28 MPa. Such dynamic load is insignificant and integrity of pipelines remains not violated. The pressure surge in pipeline connecting torus module in case of erroneous closure of automatic valve is eliminated due to operation of check valve on pipeline in torus module outlet.

Introduction

Fusion power is the power generated by nuclear fusion reactions, i.e. two light atomic nuclei fuse together to form a heavier, more stable nucleus releasing the binding energy [1]. At present, several experimental fusion reactors are under construction, among them ITER, which is built in France, KSTAR in South Korea, Wendelstein 7-X (W7-X) in Germany.

In contrast to the tokamak concept (used for ITER and KSTAR), where the poloidal component of the magnetic field is generated mainly by an induced current flowing in the plasma, in stellarators, the vacuum magnetic field for plasma vessel is produced entirely by external currents allowing steady-state operation. The stellarator W7-X is presently under construction at the Max-Planck-Institut für Plasmaphysik, Greifswald, Germany [1], [2]. The superconducting magnet system enables continuous operation, limited by the cooling water system whose capacity to remove the plasma heat load onto the wall components is designed for 30 minutes full power operation.

Prior to the commissioning of the facility its safe operation has to be proved by dedicated safety analyses. The first priority is the prevention of ingress of water into the plasma vessel; the second – to warrant the integrity of pipelines in the targets cooling / heating circuits during any initiating events. The analysis of the most dangerous LOCA event – rupture of a 40 mm target cooling pipe during plasma vessel structure heating regime (operation in the “baking” mode), related to first priority case (water ingress into plasma vessel) is already presented in few papers [3], [4], [5]. The initiating event, which potentially can lead to loss of integrity of pipelines in the targets cooling / heating circuits, is the water hammer. The water hammer effect is pressure surge wave when water in motion is forced to stop due to sudden closure of valve. In the case of sudden closure of valves, the mass of water before the closure point is still moving forward with some velocity, building up a high pressure and shock waves. The sharp change of velocity of water flow, thus the kinetic energy of water is transformed to pressure pulse.

In this paper the consequences of potential water hammer effects were analysed only for the case, when the plasma vessel is operating in the “baking” mode. “Baking” is the mode of facility operation during which the vacuum vessel structures are heated up to 150 C in order to release absorbed gases from the surfaces and to pump them out of the plasma vessel before plasma operation. The results of the presented studies may be used during the justification of the design of the coolant circuits of W7-X, which is now under construction, and to define protection measures and instructions in order to ensure safe operation.

1. W7-X target modules cooling system

The plasma vessel in W7-X facility is composed of five modules, which are divided each into two sectors to allow threading of the innermost coils during assembly (see Figure 1). The in-vessel components (modules) consist of the divertor units, baffles, panels and heat shields, control coils, cryo-pumps, port protection and special port liners, and the complex system of cooling water supply lines as well different diagnostics. [2].

The W7-X cooling system supplies 5 torus modules. Each torus module is composing of 18 horizontal and 6 vertical target modules. The horizontal target modules can be grouped in 9 upper and 9 lower target modules. The W7-X facility target modules cooling system consists of two coolant circuits: The main cooling circuit (MCC) and the so-called “baking” circuit. The MCC is used for cooling of the target modules when the W7-X facility under normal operation. As it was mentioned, before plasma operation, the target modules and other in-vessel components must be heated up in order to release and remove the absorbed gases from the surfaces. The “baking” circuit is mainly used for this purpose, when the heat, necessary for target modules heating is generated in electrical heater. There is only one pump for all target modules loops in the “baking” operation mode. Both MCC and “baking” circuits are connected together and supply water to the same target modules. More detailed description of MCC and “baking” circuits (the targets cooling / heating circuits) are described in papers [3], [4].

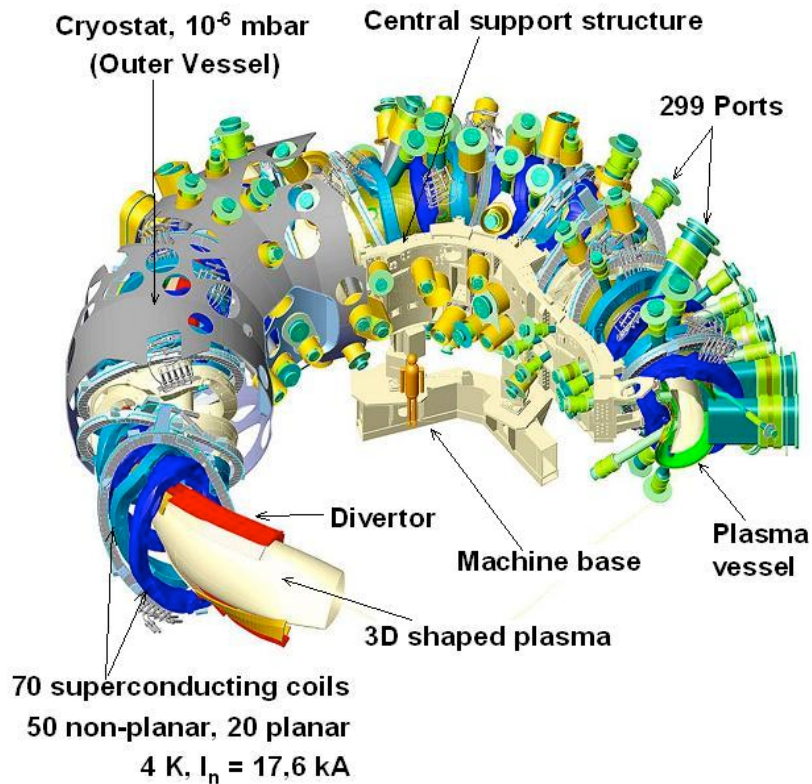


Figure 1. Fragment of W7-X torus [1]

The initial conditions during “baking” operation mode are following: the maximum water temperature is 160 °C; the water pressure is about 1.0 MPa; the mass flow of water in the “baking” circuit is 177 m³/h (44.6 kg/s); the flow velocity through the cooling tubes of the target modules during “baking” operation mode is about 1 m/s [5].

2. Development of main cooling and “baking” circuits model using RELAP5 code

For the analysis of LOCA in W7-X facility integral RELAP5/Mod3.3 code was used. RELAP5 [6] – is a “best estimate” system code suitable for the analysis of all transients and postulated accidents in Light Water Reactor systems, including both large and small-break loss-of-coolant accidents as well as the full range of operational transients. The one dimensional RELAP5 code is based on a non-homogeneous and non-equilibrium model for the two-phase system that is solved by a fast, partially implicit numerical scheme to permit economical calculation of system transients. In addition, RELAP5 can be used to solve many plant thermal-hydraulic problems. The code includes many generic models allowing to simulate general thermal hydraulic systems. The models include pumps, valves, pipes, heat releasing or absorbing structures, reactor point kinetics, electric heaters, jet pumps, turbines, separators, accumulators, and control system logic elements [6]. At the Lithuanian Energy Institute, the RELAP5 code is used since 1993 for Ignalina Nuclear Power Plant licensing purposes (for the analyses of the thermal hydraulic response of the plant to various transients).

For the analysis of consequences of potential water hammer effects in “baking” operation mode it is sufficient to develop a detailed model of the “baking” circuit. However both MCC and “baking” circuit are connected together. Thus, it was decided to develop a detailed model of both connected circuits. The measurements (pipe lengths, elevations, pump parameters, heater power and valves parameters) and the configuration of pipes (necessary for evaluation of form loss coefficients) were taken from the drawings provided by the W7-X design office. During operation in “baking” mode the valves on water supply and return lines in MCC are closed; valves on water supply and return lines in “baking” circuit are opened. The injection of water into plasma vessel through rupture in torus module connecting pipeline will lead to fast pressure increase in plasma vessel, which is operating at vacuum condition in “baking” mode. Such pressure increase is dangerous because it may raise the damage of plasma vessel components. Thus, to prevent the discharge of water in plasma vessel in case of rupture of pipeline inside vessel, the automatic valves on water supply line in “baking” circuit are closing after the pressure increase in plasma vessel is indicated. The simplified nodalization scheme of the “baking” circuit (only one out of five torus modules is shown) is presented in Figure 2. More detailed description of RELAP5 model is presented in papers [3], [4].

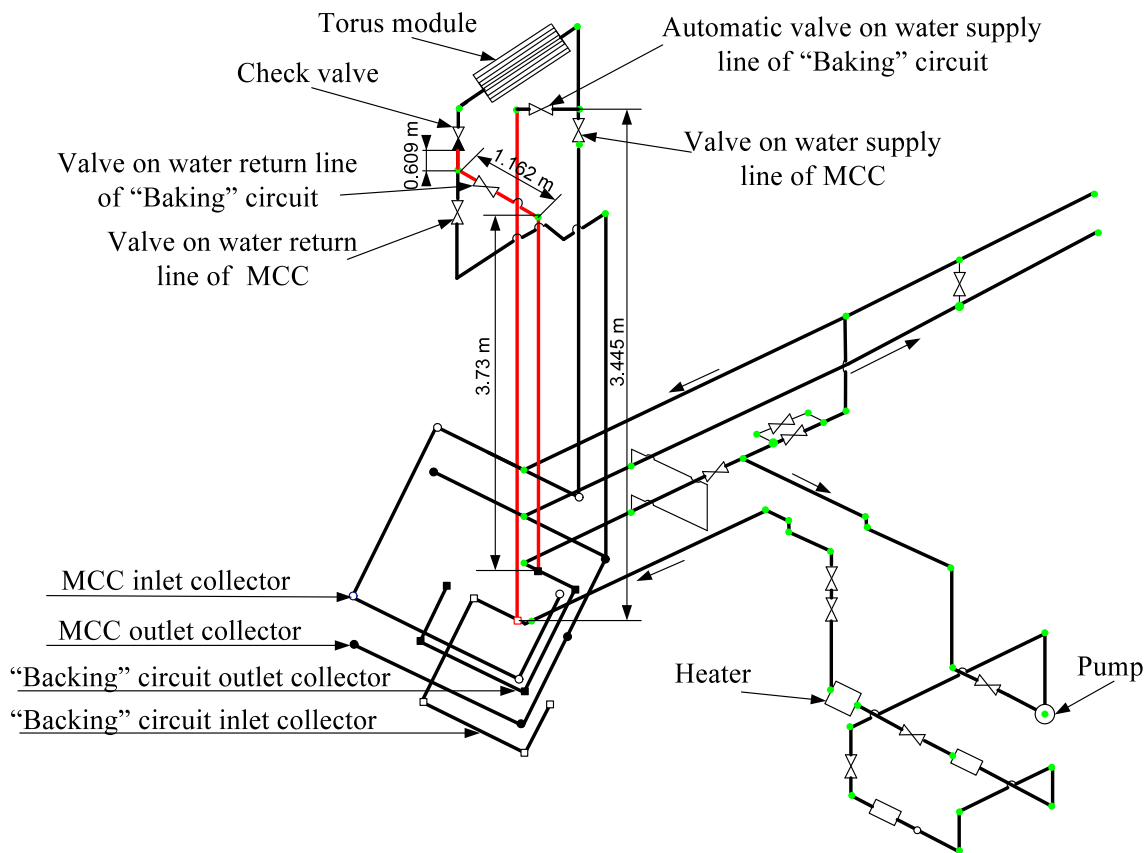


Figure 2. Nodalization scheme of the “baking” circuit

In the outlets of torus modules the special low inertial check valves are installed. These valves, manufactured by “Crane Process Flow Technologies GmbH” are working in double wing principle (see Figure 3).

In the RELAP5 code [6] the Check Valve is modelled as the junction with an on and off switch. If the valve is on, then it is fully open; and if the valve is off, it is fully closed. For the modelling of “DUO Chek II” check valve the static pressure/flow-controlled check valve model with hysteresis effect and without any leakage was selected. The selected model is proved as more stable, without less noisy and less oscillations approach, comparing to the static pressure-controlled check valve and static/dynamic pressure-controlled check valve models. From other hands, this model gives the most conservative results – the testing calculations were performed, using different possible approaches for check valve modelling. The calculation results showed, that selected “static pressure/flow-controlled check valve” model presents the highest rate of coolant oscillations.

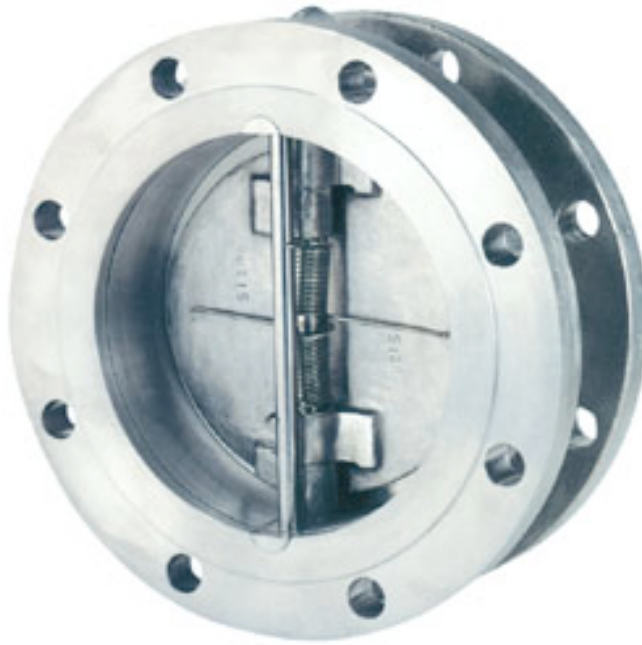


Figure 3. View of double wing check valve “DUO Chek II” manufactured by “Crane Process Flow Technologies GmbH” [9]

The model for these valves does not include valve inertia or momentum effects. The static pressure/flow-controlled check valve” model means that the valve is open by static differential pressure and close by flow reversal. Valve will open if static differential pressure across the junction becomes positive, and will close only if a flow reversal occurs (when dynamic pressure is negative).

The static differential pressure across the junction is calculated according to equation (1):

$$P_K - \Delta P_{Kg} - (P_L + \Delta P_{Lg}) - PCV > 0, \quad (1)$$

where P_K , P_L - thermodynamic pressures upstream and downstream the valve; ΔP_{Kg} , ΔP_{Lg} - static pressure head due to gravity; PCV - back pressure required to close the valve (based on calculation experience it was assumed equal 700 Pa).

The dynamic pressure is given in equation (2):

$$\frac{1}{2}(\overline{\rho v |v|})_j = \frac{1}{2}|\alpha_f \rho_f v_f + \alpha_g \rho_g v_g|_j (\alpha_f v_f + \alpha_g v_g)_j < 0, \quad (2)$$

where α_f , α_g - volume fraction of fluid (liquid and gas) in the mixture (void fraction); ρ_f , ρ_g - density of liquid and gas in the mixture; v_f , v_g - velocities of liquid and gas in the mixture.

In the system thermal-hydraulic code RELAP5 [6], according the scheme of calculation, the change of pressure inside the single volume affects the adjacent volumes only with the next time step. Therefore, for the water hammer analysis the following condition has to be satisfied:

$$\Delta l \geq a * \Delta t, \quad (3)$$

where Δl - length of a volume, m; a - sound velocity of the medium, m/s; Δt - time step of calculation, s.

The maximum value of the sound velocity for the water is approximately $a = 1500$ m/s. Thus, to fulfil the requirement of equation (3) the close attention must be paid to the control volume size, where the water hammer is expected to occur and time step of calculation. According article [7], the length of one control volume should not exceed 1 m in the modelled pipelines where water hammer is expected. It was shown in article [7], that the further decrease of length of the control volumes do not increase the pressure peaks in these volumes. In the present RELAP5 model the length of volume was taken more conservative and it is set to $\Delta l \approx 0.15$ m.

For transients, results strongly depend on the time step used [8]. Accuracy is achieved with normal time step [8] which could be calculated by equation (4):

$$\Delta t_n \leq \Delta l / v, \quad (4)$$

where v is velocity of flow in the control volume, m/s.

From the equation (4) normal time step in the analysed case is ~ 0.02 s (velocity of flow in the control volume is ~ 7 m/s). Thus, it was decided to take the maximum time step, which must be much lower than normal time step and will satisfy inequality presented in the equation (4). So maximum time step is limited to $\Delta t = 0.00005$ s and with these values the condition, presented in equations (3 and 4) will always be satisfied.

The pressure pulsations in the pipes (water hammer effect) may destroy the walls of pipes or pipe connections, welding and etc. Thus, the loading, affecting the pipes due to sharp change

of velocity of water flow (change of the kinetic energy of water to the pressure pulse) should be calculated. For a straight pipe section the normal direction of a positive velocity and a positive fluid force is directed from first to second boundary of the section and the fluid force is always parallel to the pipe axis. The reaction force due to change of water flow velocity is calculated according the equation (5):

$$F = -\frac{d}{dt} \int_0^L m * dz, \quad (5)$$

where F – reaction force, N; m – mass flow, kg/s; L – length of straight pipe section, m.

The RELAP5 code [6] calculates the values of relevant fluid-dynamic quantities (pressure, temperature, density, velocity, mass flow, gas fraction) inside and at the boundaries of each volume for every time step. The values for temperature, density and velocity are calculated separately for the liquid and gas phase. The fluid forces F_A acting on the boundaries of a straight pipe section with constant flow area is calculated with the following equations:

$$F_{A1} = -(P_1 - P_{atm}) * A - (1 - x) * (\rho_{1f} * A * v_{1f}^2) - x * (\rho_{1g} * A * v_{1g}^2), \quad (6)$$

$$F_{A2} = (P_2 - P_{atm}) * A - (1 - x) * (\rho_{2f} * A * v_{2f}^2) - x * (\rho_{2g} * A * v_{2g}^2), \quad (7)$$

where F_{A1} , F_{A2} – forces at the boundaries 1 and 2, N; A – flow area of pipe, m²; x – volumetric gas fraction (void fraction); P_1 , P_2 – pressure at the boundaries, Pa; P_{atm} – ambient pressure ($P_{atm} = 100000$ Pa); ρ_{1f} , ρ_{1g} , ρ_{2f} , ρ_{2g} – densities of the liquid and gas on boundaries 1 and 2, kg/m³; v_{1f} , v_{1g} , v_{2f} , v_{2g} – velocities of the liquid and gas on boundaries 1 and 2, m/s.

The resulting (reaction) force due to coolant velocity change F is calculated as the sum of forces at the boundaries 1 and 2 (F_{A1} and F_{A2}):

$$F = F_{A1} + F_{A2}. \quad (8)$$

3. Results of analysis

As it was mentioned, in this paper the consequences of potential water hammer effect were analysed only for the case, when the plasma vessel is operating in the “baking” mode. Usually, the water hammer phenomenon is related to the sudden change of coolant flow velocity. Such change may appear due to fast opening / closure of valves. Thus, in this paper the events related to the fast closure of automatic valves on water supply line in “baking” circuit and events, leading to closure of check valve on torus module outlet (see Figure 2) are analysed. Three analyses are presented:

- analysis of pressure surge in pipelines upstream automatic valve in case of this valve erroneous closure;

- analysis of pressure surge in pipeline connecting torus module in case of erroneous closure of automatic valve;
- analysis of pressure surge in pipeline downstream check valve in case of break of pipe upstream check valve and fast closure of this valve.

Analysis of pressure pulsations in pipelines upstream automatic valve. The initiating event in this case is the erroneous closure of automatic valve. Because all five valves in all torus modules are activated on the same logic – they are closing according pressure increase in plasma vessel, the failure in logic and erroneous closure of all automatic valves on water supply line in “baking” circuit is assumed as initiating event. Real closure time of automatic valve is approximately 5 seconds, the close time equal 1 second was assumed using the conservative approach. There is 3,445 m length and 0,072 m inner diameter straight vertical pipe, connecting the unit of automatic valve with the “baking” circuit inlet collector (see Figure 2). The pressure pulsation and reaction force in this pipe in case of erroneous closure of automatic valve is presented in Figure 4 and Figure 5. As it is seen from presented figures the pressure peak in pipeline upstream automatic valve reaches 3.7 MPa, the reaction forces due to stoppage of water flow (the velocity of water is decreasing from 2.4 m/s down to 0 within 1 s) reaches 0.5 kN. This reaction force affects the unit of automatic valve and the “baking” circuit inlet collector. If we assuming the activated area equal to the pipe flow area (0.00408 m^2), the force raises the loading equal to 0.1224 MPa. Such dynamic load is insignificant and integrity of pipelines remains not violated.

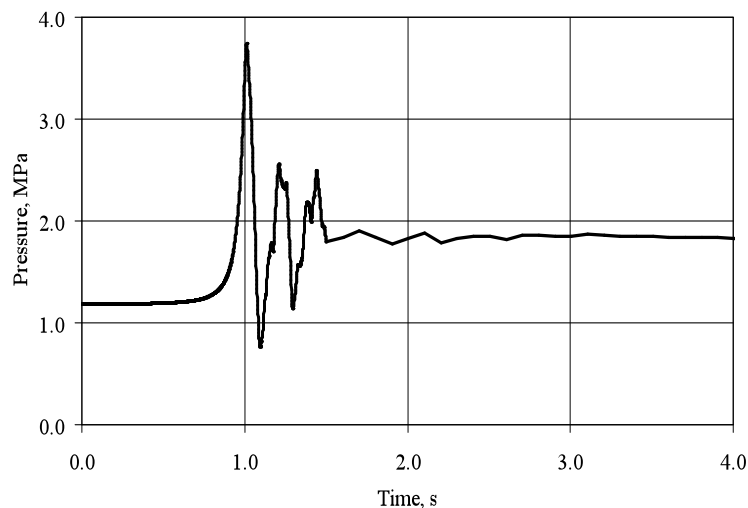


Figure 4. Pressure pulsation in pipe upstream automatic valve in case of this valve erroneous closure (closure time – 1 s)

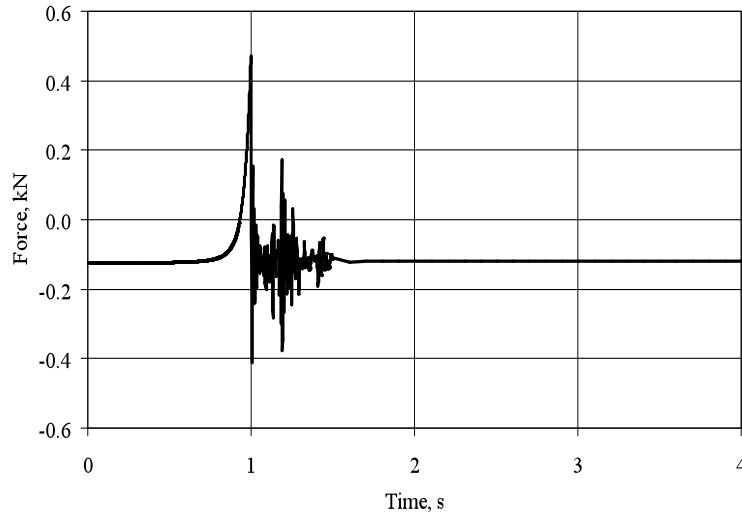


Figure 5. Reaction force in pipe upstream automatic valve in case of this valve erroneous closure (closure time – 1 s)

Analysis of pressure pulsations in pipelines connecting torus modules. The analysis of water hammer test, performed at UMSICHT test facility [10] demonstrated strong pressure pulsations in the pipelines downstream fast closed valve. The analysis of special test for the water hammer phenomena analysis in the Fraunhofer Institute for Environmental, Safety and Energy Technology (UMSICHT) at Oberhausen, Germany was performed by employing RELAP5/Mod3.3 code [6]. The results of analysis showed, that after the valve has been closed, the pressure in pipe downstream valve decreases to the saturation pressure, which is close to vacuum (within the first 3 seconds the tube is almost completely empty). The steam fraction increases in this section of pipe. Later the water flows back in the slug, the steam fraction decreases rapidly and, then the steam is completely condensed. Therefore, the pressure peak at this pipe section downstream the closed valve is observed (at $t = 3.2$ s) and it is caused by the collapse of the void in this place. This pressure wave travels through the pipeline. It is reflected at the entrance into the storage tank used in UMSICHT experimental facility, and returns as the wave of pressure decrease. When this wave reaches the closed valve, a new cavitation bubble is generated. This process repeats for several times and a series of water hammers with the decreasing amplitudes is observed. The pressures of the following cavitation processes decrease with time due to the friction between the liquid and structure. Taking into account experience from the UMSICHT test modelling, the possibility of pressure pulsations in pipelines connecting torus modules was analyzed. At first, more conservative – hypothetical situation was analyzed (it was assumed that the automatic valve closes very rapidly – within 0.05 s and the check valves at the torus module outlets are not installed. As it is presented in Figure 6, the closure of valve leads to fast pressure decrease from 1.13 MPa down to 0.6 MPa and appearance of small steam bubbles in pipeline downstream valve (see Figure 7). Comparing, to UMSICHT test facility, the circuits of torus modules cooling in W7-X facility is more complicated, with parallel channels, branches, connected pipelines with very different flow areas, heaters, etc. Thus, the pressure pulsations in pipelines in W7-X case are few times smaller and oscillation frequency is few times higher. The highest pressure peak in this hypothetical case reaches 1.95 MPa (see Figure 6). In reality, the low inertial check

valves, installed downstream torus modules, are opening for very short time to release water in case of pressure increase and closing due to opposite flow (see Figure 8). Thus, in real activation of automatic valve (close time no shorter as 1 second) and availability of check valves, the pressure pulsation in pipelines connecting torus modules do not appears. The very small increase of fraction of steam in the pipelines downstream valve are observed in Figure 7. This appears due to fast pressure decrease in this section of pipelines (pressure decreases from 1.13 MPa down to 0.64 MPa), this do not leads pressure oscillations due to availability of check valve.

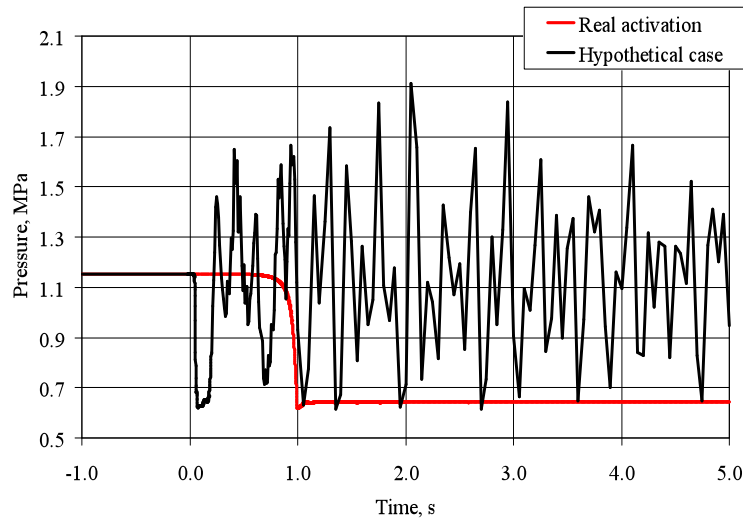


Figure 6. Pressure behaviour in pipelines connecting torus modules (downstream automatic valve) in case of this valve erroneous closure. In hypothetical case valve closure time is 0.05 s, the check valves at modules outlet are not installed. In real case, the closure time of automatic valves is ≥ 1.0 s and check valves available

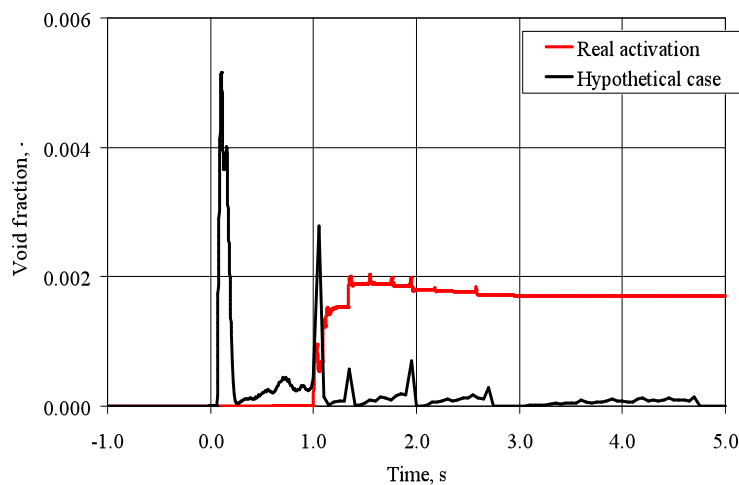


Figure 7. Change of steam fraction in pipelines connecting torus modules (downstream automatic valve) in case of this valve erroneous closure. In hypothetical case valve closure

time is 0.05 s, the check valves at modules outlet are not installed. In real case, the closure time of automatic valves is ≥ 1.0 s and check valves available

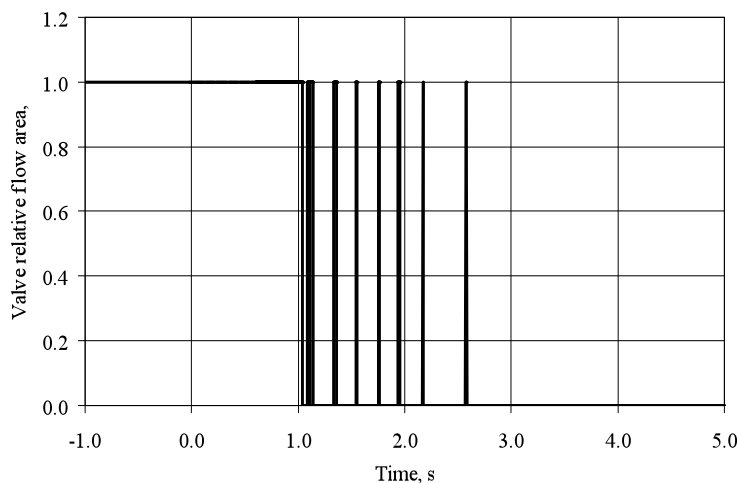


Figure 8. Change of relative check valve flow area in case of erroneous closure of automatic valves on torus modules outlet

Analysis of pressure pulsations in pipeline downstream check valve in case of break of pipe upstream check valve. In this case the initiating event is the full break of 0.263 m diameter pipe upstream check valve (in torus module outlet). Due to fast pressure decrease in pipe upstream check valve, the direction of flow changes, that leads to closure of check valve. The schematic configuration of pipelines downstream check valve is presented in Figure 2. There is 0.263 m diameter and 0.609 m length straight vertical pipe section with branch, 1.162 m length straight horizontal pipe (0.0849 m inner diameter) with opened valve on water return line in “baking” circuit and 3.73 m length straight vertical pipe (0.0721 m inner diameter) connected to “baking” circuit outlet collector. The fast change of flow direction in these pipes will lead to pressure pulsations. Analysis of these pressure surges was performed by employing RELAP5/Mod3.3 code. The initiator of pressure pulsations is the fast closure of low inertial check valve, working on double wing principle (see Figure 3). The initial mass flow rate through the single module in “baking” operation is approximately 9 kg/s, the initial water velocity in 0.263 m diameter pipe is 0.18 m/s. The break of pipe upstream check valve leads to change of flow direction through check valve and closure of this valve within 0.0003 s (see Figure 9). The pulsation of pressure inside pipeline downstream check valve is presented in Figure 10. The reaction forces due to changes of water flow in three different sections of straight pipes are presented in Figure 11. As it is seen from figure, the highest force is in the biggest diameter pipe, connected to check valve. The maximum value of force reaches 15 kN. This reaction force affects the unit of check valve and the branch. If we assuming the activated area equal to the pipe flow area (0.054325 m^2), the force raises the loading equal to 0.276 MPa. Such dynamic load is insignificant and integrity of pipelines downstream check valve remains not violated.

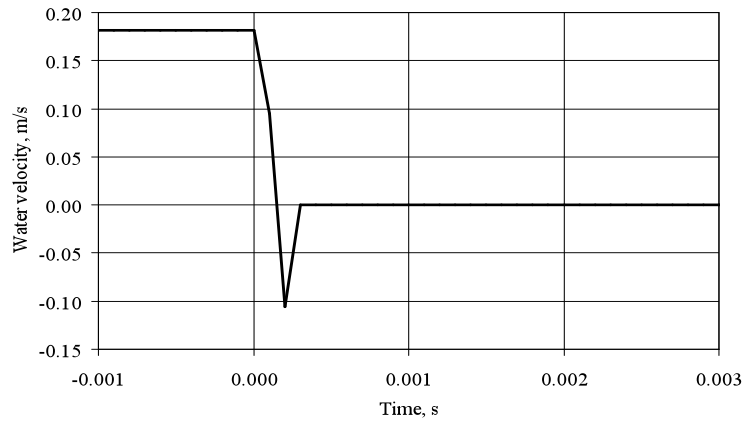


Figure 9. Behaviour of water velocity through check valve. The break of pipe upstream check valve

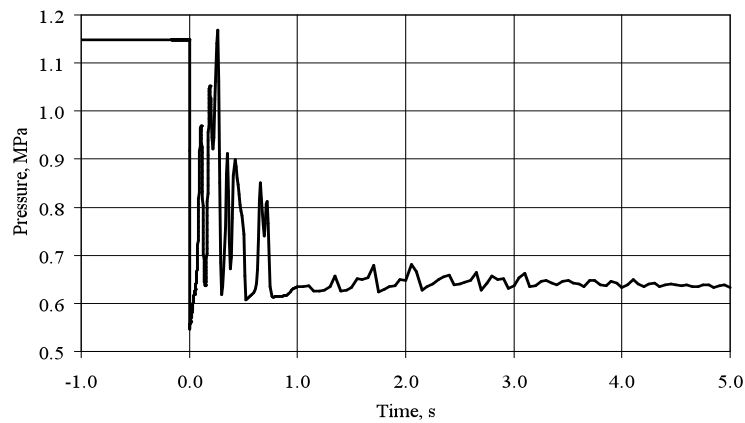


Figure 10. Pressure pulsation in pipe downstream check valve in case of pipe upstream check valve break

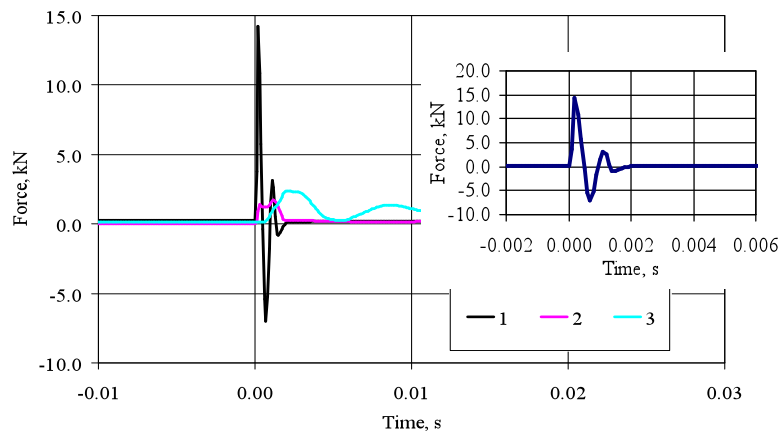


Figure 11. Reaction force in pipe downstream check valve in case of pipe upstream check valve break: 1 – 0.263 m diameter pipe; 2 – 0.0849 m diameter pipe; 3 – 0.0721 m diameter pipe

4. Conclusion

In this paper the consequences of potential water hammer effects were analysed only for the case, when the plasma vessel is operating in the “baking” mode. For the analysis the thermal-hydraulic model of target (torus) modules cooling / heating systems in W7-X facility was developed using RELAP5/Mod3.3 code.

Three analyses are presented:

- analysis of pressure surge in pipelines upstream automatic valve in case of this valve erroneous closure;
- analysis of pressure surge in pipeline connecting torus module in case of erroneous closure of automatic valve;
- analysis of pressure surge in pipeline downstream check valve in case of break of pipe upstream check valve and fast closure of this valve.

The results of analyses demonstrated, that due to fast erroneous closure of automatic valves on water supply line of “baking” circuit (inlet into torus module), the maximum dynamic loading due to stoppage of water flow equal to 0.1224 MPa. Such dynamic load is insignificant and integrity of pipelines remains not violated.

The pressure surge in pipeline connecting torus module in case of erroneous closure of automatic valve is eliminated due to operation of check valve on pipeline in torus module outlet.

In the case of full break of 0.263 m diameter pipe upstream check valve (in torus module outlet), the pressure surges occurs in the pipelines downstream check valve after fast closure of this valve. The maximum dynamic loading due to this pressure pulsation is equal to 0.276 MPa. Such dynamic load is insignificant and integrity of pipelines remains not violated.

The results of the presented studies may be used during the justification of the design of the coolant circuits of W7-X, which is now under construction, and to define protection measures and instructions in order to ensure safe operation.

5. Acknowledgments

This paper was prepared on the basis of work, which was carried out within the framework of the European Fusion Development Agreement and supported by the European Commission. This work is also supported by the Agency for International Science and Technology Development Programmes in Lithuania.

The authors of the paper would like to express their gratitude for D. Naujoks from Max Planck Institute for Plasma Physics, who contributed to the performed analysis with valuable comments and scientific support.

6. References

- [1] H.-S. Bosch, A. Dinklage, T. Klinger, R. Wolf, the W7-X Team, “Contributions to Plasma Physics”, DOI: 10.1002/ctpp.201090001, 2010.
- [2] B. Streibl, “Manufacturing of the W7-X divertor and wall protection”, Proceedings of 23rd Symposium, Fusion Technology, Venice, Italy, 2004.
- [3] T. Kaliatka, A. Kaliatka, T. Kačiagavičius, D. Naujoks, „Analysis of the processes in the target cooling system of the W7-X fusion experiment”, Kerntechnik, ISSN 0932-3902. 2010. Vol. 75, Iss. 5, p. 255-263.
- [4] A. Kaliatka, M. Povilaitis, E. Urbonavičius, T. Kaliatka, “Analysis of the consequences of targets feeding pipe rupture in Wendelstein 7-X experimental nuclear fusion device“ Proc. of 8th Int. Topical Meeting on Nuclear Reactor Thermal Hydraulics, Operation and Safety NUTHOS-8, October 11-13, 2010. Shanghai, China, 2010, p. 12.
- [5] L. Topilski, “Consequences of the W7X in-vessel coolant pipe break at baking conditions”, Report 1-NBF-T0015, Max-Planck-Institute for Plasma Physics, Greifswald, 2006.
- [6] C.D. Fletcher, et. al., “RELAP5/MOD3 code manual user’s guidelines”, Idaho National Engineering Lab., NUREG/CR-5535, 1992.
- [7] T. Kaliatka, “Analysis of water hammer effect in W7-X facility” 7th annual conference of young scientists on energy issues CYSENI 2010, May 27-28, 2010. Kaunas: LEI, 2010. ISSN 1822-7554, p. 526-536.
- [8] I. Tiselj, G. Cerne, “Some Comments on the Behavior of the RELAP5 Numerical Scheme at Very Small Time Steps,” Nuclear science and engineering, 2000. ISSN 0029-5639, vol 134, n 3, p. 306-311.
- [9] http://www.craneflow.de/Produkte-alt/Produkte/DUO-CHEK_II-Ruckschlagklappen/duo-chek_ii-ruckschlagklappen.html
- [10] A. Kaliatka, E. Uspuras, M. Vaisnoras, “Benchmarking analysis of water hammer effects using RELAP5 code and development of RBMK-1500 reactor main circulation circuit model” Annals of Nuclear Energy, ISSN 0306-4549, 2007, Vol. 34, p. 1-12.