Introduction to Engineering of CASTOR Tokamak

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Abstract

Introduction to tokamak concept of plasma confinement, brief history of tokamak CASTOR, parameters and basic engineering description of CASTOR tokamak, modifications made since TM1 tokamak, possible future of the device

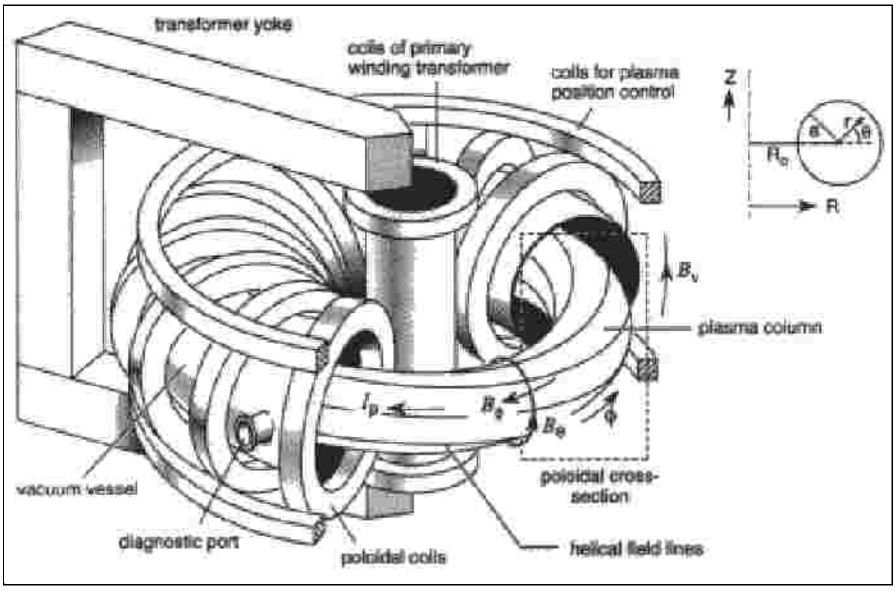
1 Introduction

The development of fusion research in all over the world resulted in demand for more fusion scientists and engineers. This is the reason why there has been opened a new curriculum on Nuclear and Physical Engineering Faculty of Czech Technical University. Recently, the experimental tokamak was moved here from Institute of Plasma Physics of Czech Academy of Sciences (IPP CAS). Influenced by aforementioned events, the authors of this paper gave themselves an objective to introduce the transferred tokamak CASTOR to students of Czech Technical University (CTU).

This paper contains a brief history of TM1 tokamak, which has been renamed to CASTOR after moving to Prague, listed with engineering modifications made on the device. Since this work covers very basic of the device engineering, there is briefly explained the tokamak concept of plasma confinement. The chapter is then followed by more in-depth explanation of each subsystem of the device. In the last chapter there is discussed the possible future of the device. Most important informations are revised in the conclusion, however, for the full understanding of the functions of the device, it is strongly recommended to read the chapter on subsystems as well.

2 Tokamak concept

There are several possible methods being discussed to achieve a successful plasma confinement. Tokamak concept is one of them. As seen on (Fig. 1), the dominant feature of tokamak device is, without doubts, its toroidal shaped vacuum-exhausted chamber. Unlike some other of the confinement concepts, the closed vessel helps to prevent plasma to escape the reactive area and to cool itself down by reacting with the cold chamber walls. Around the toroidal chamber, there are several coils of toroidal field generation placed. Together with plasma current they keep plasma particles confined in the chamber, since plasma has a very strong response to magnetic field.



(Fig. 1)
Tokamak device schema (abridged from wikipedia)

Both toroidal field and field induced by the plasma current together make appropriate bended magnetic field good for plasma confinement. To keep the plasma confined by magnetic pressure as long as possible there are also integrated stabilization coils generating poloidal magnetic field. A transformer is also integrated in a device. Its primary winding is called central solenoid, while the secondary winding is the plasma ring itself. The main purpose of the transformer is to generate the plasma of a neutral gas injected into vacuum exhausted chamber. For this purpose, glow discharge is to make a local charge. For data acquisition purposes, there are integrated several different diagnostic ports into vacuum vessel.

2 Past modifications of the device

The device was originally called TM1. Designed and constructed in Kurchatov Institute of Nuclear Research, it was one of the first operational tokamaks in the world. The original concept of the device did not include poloidal field coils of stabilization however it was believed that integrating one more layer of vacuum into the chamber would help to achieve demanded stability of plasma ring. The capacitor battery for toroidal field coils and transformer filled several rooms. Some time later, there was integrated a microwave heating system and the device was renamed to TM1-MH. The microwave heating, in addition to ohmic heating had to heat the plasma further. The wave frequency had magnitude between lower hybrid frequency and electron cyclotron frequency. The waves would be slowed down in the plasma ring and thanks to Landan's dampering, they should be giving their energy to the electrons of the plasma, increasing the plasma temperature.

After the device was moved to IPP CAS on September 1977, thanks to cooperation between the Kurchatov Institute and IPP, some changes in the engineering took place. The microwave heating system has been left in Russia, alongside with the most of the oil capacitors of the toroidal field generation, since there was not enough room in the new tokamak hall. However, a few years later, the device went under further reconstruction. The vacuum vessel had been replaced for a new one, the layer of vacuum between the liner and coating had been fully removed and there had been integrated feedback stabilization system instead. The power supply was substituted for a stronger one. The ignition was replaced with a glow discharge. Between the years 1977 and 2007 there have been several small changes over the device engineering as well, since the technology went further, such as new diagnostics sensors had been used.

In the end of 2007 the device was transferred to Faculty of Physical and Nuclear Engineering of CTU. Now there are being discussed further modifications of the device, for example improved way to distribute the power to the toroidal field coils or removing the unnecessary diagnostics sensors. The works on the reanimation of the device have started on the 14th of July 2008.

3 Subsystems of the device

Overall, the device can be divided into several sections:

1. Vacuum vessel
2. Vacuum exhaustion system
3. Work gas supply
4. Transformer
5. Coils of toroidal field generation
6. Feedback stabilization of plasma column
7. Power supply for the coils and transformer
8. Control panel and diagnostics

3.1 Vacuum vessel

The toroidal shaped chamber of main radius of 0.4 m and secondary radius of 0.1 m, is made of two layers with a free space between, of which both can be disassembled into two sections, if necessary. The first layer, which contains the plasma column, is called liner. The liner is toroidal shaped vessel made of melted cylindrical waved tin-plate segments, 0.5 mm strong, with radius of 0.085 m. The waves help to eliminate heat dilatation, increase the resistance of the plate and help to support the construction. It is thanks to the way of the melting, that liner can be disassembled into two sections, however, this had happened only once yet.

The second layer of the vessel is made of copper coating and completely covers the liner. The coating is about 20 mm strong, water cooled. The coating used to contain the second vacuum layer of vacuum, however this function is not used anymore. The coating is now used to stabilize the plasma ring position by inducing Foucalt currents and to hold coils of toroidal field stabilization.

3.2 Vacuum exhaustion system

To obtain plasma of requested experimental parameters, there must be high purity of working gas present. This is obtained by injecting the purified work gas into the vacuum exhausted vessel. The vacuum on CASTOR is kept only in the liner and used to be 10^{-5} Torr strong. It is necessary to exhaust the fore vacuum by RV1 rotational pump, before using the stronger TMP turbo molecular pump, which replaced the less pure diffusional pump used in TM1 tokamak. To obtain even better purity of vacuum, the exhausting device is being heated. It is known that by heating the components the reluctant gases and even small solid particles are being released and can be then exhausted. The level of exhaustion is measured by vacuum measure, which is divided into two independent sections, one measuring the fore vacuum, while the second is measuring the main vacuum.

3.3 Work gas supply

To obtain plasma state of matter, its gas state is needed. There have been used several different gases through the operations of the device, but in the most of the runs was used H_2 gas. There was also used Deuterium and Helium gas, few times before. The supplied gas can be of two levels - classical and purified, which are kept separately. The initial state of gas is neutral, so it is ionized by glow discharge to obtain local charge, which can be then distributed by transformer to the whole volume of the gas.

3.4 Transformer

As it was mentioned in previous chapter, the main purpose of transformer is to generate plasma of a neutral work gas. The transformer is rectangular shaped, primary winding is called central solenoid and secondary winding the plasma ring itself. The circuit of transformer is also called ohmic heating. The ohmic heating is powered by two paralelly integrated batteries of capacitors. The capacitors of transformer, unlike the ones of coils, have to be discharged as fast as possible, e.g. about 5 ms.

3.5 Toroidal field generation coils

As it was said, in tokamak device, the plasma in vessel has to be magnetically confined. That is mainly achieved by magnetic pressure of field generated together by plasma ring itself and the toroidal field generation coils.

There are 28 copper coils placed around the coating altogether. Each coil has 8 bends and has about in 30 cm diameter. Hence the small radius of vacuum vessel and large number of toroidal field coils, there is high density toroidal field (almost homogeneous) presented in the device. Toroidal field generation subsystem used to be charged by 1200 oil capacitors with overall capacity of 0.18 F, in the TM1 time. The discharging of the LC links, unlike of the transformer power source, has to take as long possible. When the LC links are fully discharged, the toroidal field, and thus the magnetic pressure, disappears and plasma can no longer be confined.

3.6 Feedback stabilization

Since the plasma is a highly unstable state of matter, the ripple effects appear. These have very negative impact on plasma stability and length of confinement period. To keep plasma column stabilized as long as possible, there used to be integrated another layer of vacuum (see vacuum vessel paragraph). Also, the induction of Foucalt currents in coating helps to stabilize plasma as well. However, the main subsystem is the feedback stabilization. The detection subsystem, made of 6 Mirnovov coils, 4 for horizontal and 2 for vertical localization, sends signals to control-regulation system. This is made of transistor-like automatic computer, however, there is intended to digitalise the procedures, so that the control system could be further modified. After the signal is processed in control computer, the two helping quadrupole windings then make appropriate vertical and horizontal field. The result is either the stabilization of plasma column location or pushing the instability by magnetic pressure back to the plasma ring.

3.7 Power supply and distribution

To generate and distribute discharge to the coils and transformer, there are two independent subsystems – toroidal field generation (LC links) and transformer capacitors, present. Toroidal field generation subsystem used to be charged by 1200 oil capacitors with overall capacity of 0.18 F. The length of their period used to be 140 ms. Together with coils they make LC links. After transfer to Prague and modifications in the engineering of the device, the capacitors have been changed for stronger ones and their number decreased. To transport the discharge from the capacitor to coils, there were used 12 thyristors integrated to 12 coaxial cables. This was mainly because of maintenance reasons, since it was thought that using more routes to distribute discharge would be more considerable towards the thyristor-discharging safety lock. However, after disassembly of LC link on CTU, it was shown, that only first two locks have been used by the discharge all the time, so using a single coaxial is discussed to be used. The optimal period for LC links to hold toroidal field on CASTOR was 30 ms. The primary winding of transformer was supplied by two parallely integrated capacitor batteries, first of 5 kV for plasma ring formation, second of 450 V for maintaining the plasma current and ohmic heating of the ring.

3.8 Diagnostics and regulation

Hence the tokamak device is impulse-operating device, all the diagnostics must be thus adjusted to it. The only exception is the vacuum measure, since it is not used when the device is in operation (see 3.2 chapter). Other diagnostic measures are usually used to measure the parameters of plasma column, such as voltage, or spectroscopy measurements. For measuring of heating wave there used to be integrated two Langmuir probes and for measuring of the toroidal field current it is used the Rogowian belt, which covers the coating in vertical direction.

To control the diagnostics, vacuum exhaustion, charging and discharging of capacitors there is used single control panel. The main regulated parameters of device are the pressure (and thus the temperature) of work gas, voltage of capacitor battery and generation of transformer field. The currents in stabilization coils are regulated by their own system (see above).

4 Possible future of the device

The current location of the device is the underground cellar of Nuclear and Physical Engineering Faculty of CTU. During summer 2008, the works on reanimation of the device had begun. The tokamak was given a new name – GOLEM, and is going to be used solely for educational purposes. On autumn 2008, the grant request is going to be sent. Should the reanimation of the device be successful, it is going to be used for experimental exercises of students of Thermonuclear fusion engineering curriculum, however it is not excluded that students of other universities, namely Karl University, will do experiments with the device as well. Among the possible further modifications that are being discussed are Internet connection to control and regulation system, integration of webcams in the tokamak cellar, digitalization of feedback system regulation, use of stronger capacitor batteries and modification of LC links discharging.

5 Conclusion

The aforementioned device bears all the characteristic signs of tokamak concept of plasma confinement. Injected gas has almost always been H_2. However this gas is neutral and thus is ionized by glow discharge and transformer. Field generation coils of relative high density (28 flat copper coils altogether) and plasma column current creates the appropriate field for plasma confinement by its magnetic pressure. The plasma is further heated by transformer and stabilized by Foucalt currents of coating and by two helping quadrupole windings of feedback stabilization system. Hence the impulsive character of tokamak device, all the diagnostics and regulations have been adjusted to it.

Since the device TM-1 was constructed in Kurchatov Institute of Nucear Research, moved to Institute of Plasma Physics in Prague and renamed to CASTOR and finally transferred to CTU under the name GOLEM, the changes in engineering took place. The number of capacitors was reduced, microwave heating was disassembled, second layer of vacuum was removed to be replaced for feedback stabilization system. Some further modifications are being discussed, while the device is currently in CTU in the state of reoperation. After that it is going to be used for educational purposes of Thermonuclear fusion engineering curriculum students.

6 Acknowledgments

First of all, the authors would like to thank to ing. Vojtech Svoboda Csc. First for organizing the physical seminary, but most of all for initiating the Thermonuclear fusion engineering curriculum and obtaining the real operational tokamak from Institute of Plasma Physics for educational purposes and for all the time and work he dedicated to its cooperation. Authors would also like to express their gratitude to Institute of Plasma Physics as well, since they have given the CTU a device, they have been experimenting on for a many years and providing whole documentation as well.

7 References

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