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TF coil structure in Alborz Tokamak, from design to mounting

Saeideh Koohestani[a,*], Reza Amrollahi[b]

[a] Department of Physics, Najafabad Branch, Islamic Azad University, Najafabad, Iran
[b] Department of Energy Engineering and Physics, Amirkabir University of Technology, Tehran, Iran

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ABSTRACT

The structures which support the coils and other devices play an essential role in the performance of Tokamaks. Since Toroidal Field (TF) coil movement results in the magnetic field variation and plasma fluctuation, a robust structure has to be designed to prevent excessive TF coil deformations. Other issues such as the selection of a non-ferromagnetic material should be obeyed in the structure design. In this paper, the design, analysis and manufacture of the support structure for TF coils of Alborz Tokamak have been reported. The TF coil support system was designed with regard to all the technical points. After designing the structure, the strength of the system was investigated, using the Abaqus software; and to determine the input electromagnetic loads, Comsol program was used. The result of the analysis indicated the appropriate strength of the system. Accordingly, the support structures were manufactured. The primary shapes of the structures were constructed via casting and then the structure shape was finalized by Computerized Numerical Control (CNC) machining. During manufacturing, attempts were made to maximize the dimensional precision. The detailed report of the mentioned steps has been presented in this paper.

1. Introduction

The Alborz Tokamak is a D-shaped cross section Tokamak that has been under construction in Amirkabir University of Technology since 2012 [1]. This system contains TF coils (for plasma stability), PF coils (for the control of the plasma position and shape), central solenoid coils (for the premier plasma construction and inspiring the plasma current) and structural components (which support the mentioned coils and prevent the system from adverse motions). Since TF coils play an essential role in the Tokamak operation, they should be designed accurately [2]. In Alborz Tokamak, TF coils are placed around the plasma chamber and hence, are affected by the forces resulted from magnetic fields. Since any motion in the coils will result in the magnetic field variation, it is necessary for the coil structures to resist in-plane and out-of-plane forces, which are the most critical loads on the TF magnet system. Therefore, the coils are planned to fit in support structures. Previously, some reports have discussed the support structure design issues for some Tokamak TF coils such as KSTAR [3], TPS [4], CFETR [5] and ITER [6]. According to the mentioned literature, an appropriate support structure has been provided for Alborz Tokamak TF coils. These support structures have been designed, with regard to all technical issues. Additionally, in order to investigate the structural stability of Alborz Tokamak magnet system, structural analysis has been conducted. To analyze the structure, 3D model of the magnetic system is developed to evaluate the behavior of the system. In this paper, the report of the design, analysis and manufacture of TF coils support of Alborz Tokamak is presented.

2. Toroidal coils in Alborz Tokamak

TF coils are the main parts of Alborz Tokamak which consist of 16 rectangular coils, connected electrically in series and arrayed toroidally which lead to the magnetic field of 1 T at the plasma center. Each toroidal coil is a set of 10-loop belts with the width of 50 mm made of copper. Thickness of each belt is 5 mm. The coil sets are rectangular with the outer dimensions of 480*950 mm^2. A set of TF coils is shown in Fig. 1. The power supply used in this system is a capacitor bank with the capacity of C = 1.32 m F and V_{max} = 14 kV. This power supply results in the electric current density of 50 MA/m^2 in TF coils. The TF coil current in Alborz Tokamak reach to 50 MA/m^2 in about 1 ms (the TF coil current in each belt reach to 12 K A) and then goes down to zero. The PF coil current in each ring also reach to 20 K A.

3. TF coil support structure design

In this section, the design of TF coil support structure is proposed.

* Corresponding author.
E-mail address: saeidehkoohestani@gmail.com (S. Koohestani).

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Fig. 1. A set of toroidal coils consisted of 10-loop belts in Alborz Tokamak.

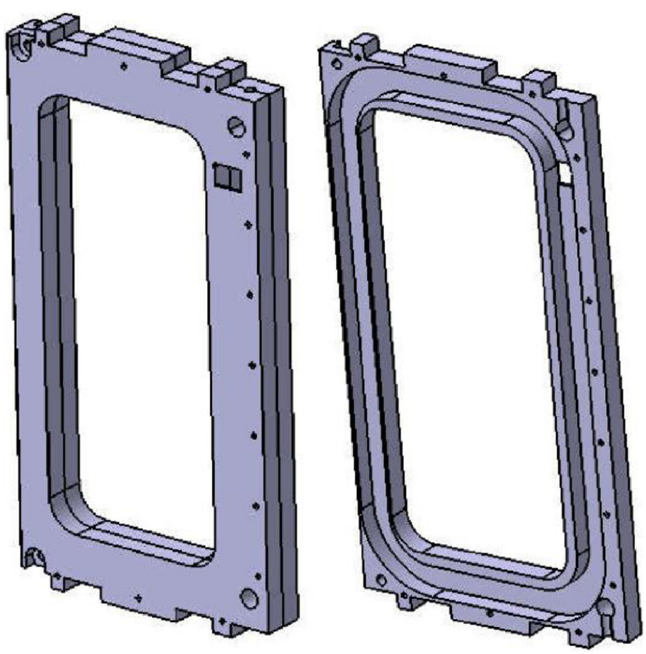

Fig. 2. 3D view of the TF coils support structure design.

Since displacement of TF coil should be controlled by the support structure, the TF coil has to completely fit in the support structure. Hence, a support case has been designed in two parts with bolt connections to hold the coils and prevent them from any movement. The material of structure should resist rusting, be cleaned easily, not be ferromagnetic, and be well degassed. According to the mentioned parameters, 7075 aluminum alloys have been chosen for the support structure material. Based on the available spaces in Tokamak machine and considering the possibility of assembling and manufacturing, the support case design has been finalized as shown in Fig. 2. As mentioned above, the dimensions of the groove within the support structure are compatible with the corresponding values in TF coil, in order to have a robust TF magnet structure.

As observed in Fig. 3, some holes are considered in the support structures where the ends of each TF coil come out from them. Each coil end is connected to beside one as shown in Fig. 3 in order to make a series connection.

Mylar 250 μm along with a polyester cover and fire-resistance fabric are employed for insulation between belts and the gap between coil and the support is filled by Polyurethane.

In order to restrain the movements of the support structure, the magnet system is connected to the gravity support through the inner and outer rings, as shown in Fig. 4. The outer and inner rings at the bottom of the machine are fixed to three stands. Therefore, the support structure movements are fixed at the place of interactions with the rings.

As demonstrated in Fig. 5, the inner ring and each support structure are connected via a holder. The holder which is made of stainless steel is fixed to the support structure and the inner ring through the bolt connections. As observed in Fig. 5, each support structure is fixed to the outer ring through a bolt. A kind of washer is placed between this connection which damps the impact loads (such as those in seismic events).

4. Load distribution in TF coils

In order to have an accurate analysis of the TF magnet system, the load distribution should be thoroughly determined. During the normal operating conditions, the TF magnet system has to withstand the EM loads resulted from the interaction of its current with toroidal and poloidal fields. The interaction with toroidal field leads to a force distribution. As a result of this load distribution, each coil faces a strong internal tension along its length which is certainly one of the most important loading conditions for the whole machine. When the CS or the PF coils are energized, the interaction of the TF magnet current with the corresponding magnetic field results in a load which is normal to the plane of each coil.

Based on the value of PF coil current, the corresponding magnetic field would be at maximum 0.01 T in Alborz Tokamak chamber. In comparison with the magnetic field resulted from TF coil (it will be demonstrated that the corresponding magnetic field value reach to 1 T), the magnetic field resulted from PF coils is very low (about 0.01 of the TF coil magnetic field). Hence, the out of plane load applied to the TF coils, which mainly is attributed to the interaction of the TF coil current with the PF magnetic field does not produce a significant effect on the machine structures and this load is negligible, compared with the in-plane loads (which come from the interaction of TF coil current with TF magnetic field). Therefore, the effect of out of plane loads on the structure stability has not been considered for analysis.

In order to determine the load distribution within the TF magnet system, all 16 rectangular TF coils have been modeled in Comsol software [7]. The relative electric current density has been assigned to the coils and stationary solver has been used to calculate the Lorentz load distribution on the coils. The magnetic field distribution obtained from solving the TF magnet system in Comsol is shown in Fig. 6.

The obtained load distributions on the surfaces of the TF coil are presented in Fig. 7. The plots of Fig. 7 show the variations of the load components along the corresponding dimensionless surface lengths. It is assumed that the load distributions along the width of surfaces are constant. It is worth mentioning that, the load distributions on the surfaces #5, #6 and #7 are shear loads, while the rest are pressure loads. The maximum value of the load is more than 400 K Pa, applied on the center of surface 1, as shown in Fig. 7.

In order to show how small the out of plane loads are in comparison with the in plane ones, the out of plane and in plane load applied to the