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Structural integrity analysis for final design of ITER gas fueling manifold

Chengzhi Cao[*], Yudong Pan, Tao Jiang, Bo Li, Wei Li

Southwestern Institute of Physics, 610041 Chengdu, China

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ABSTRACT

The Gas Fueling (GF) manifold is a major subsystem of the ITER gas injection system and it is designed to deliver fueling gases from tritium plant for initiating, maintaining or controlling plasma. According to the load specifications, the detailed structural analysis of ITER GF manifold have been performed to assess the design and structural integrity. The results show that the GF manifold is safe under all load combinations and the structural integrity requirements are well satisfied. This paper provides briefly the results of structural analysis for ITER GF manifold final design review.

1. Introduction

The Gas Fueling (GF) manifold is a major subsystem of the ITER gas injection system and is assembled in the tokamak building. As a fundamental unit of the ITER tokamak, the functions of the GF manifold are to deliver the fueling gases from Tritium Plant (TP) for initiating, maintaining or controlling plasma [1–4]. Due to the complicated operation condition, the GF manifold has to sustain the designed loads including dead weight, pressure, thermal load and seismic load. Based on the specified load combinations and established assessment methodology, all relevant results of mechanical and thermo-mechanical analyses under different operation scenarios and fault conditions are checked and discussed.

2. Description of finite element (FE) analysis

2.1. Design description

The basic configuration of the GF manifold [5], as shown in Fig. 1, is dictated by the locations of the connected Gas Valve Boxes (GVBs) and Disruption Mitigation System as well as the interfacing points with the TP. This results in a configuration, which is routed from the TP and through the vertical shaft and presents a similar horseshoe shape along the bio-shield at the upper (L2) and divertor (B1) levels.

As shown in Fig. 2(a), the GF manifold has a complex piping arrangement including the gas supply pipes, evacuation pipe and guard pipe. The individual gas supply pipes and evacuation pipe are routed in a secondary guard pipe, provided for both safety and mechanical protection of the internal pipes (gas supply pipes and the evacuation pipe). Each gas supply pipe is sized following the ASME B36.10/19M10S standard to provide the minimum pressure drop at the maximum flow rate. Stainless steel (TP 316 L) is the major material for pipes and the support structure [3,5].

In order to simplify the assembly on-site and minimize the workload, the manifold is designed in a series of basic modularized units, such as the straight section and the elbow junction. During installation processes, the components of the manifold are highly preferred to be butt-welded to ensure high reliability. As shown in Fig. 2(b), the internal support aims to bear the seismic load and dead weight of the internal pipes of the manifold. The internal supports are placed at appropriate positions and mounted onto the evacuation pipe by spot welding. The basic function of the external support is to bear the gravity of the manifold. The ITER design group provides these currently available embedded plates for connecting with the external supports.

2.2. FE models

The analysis models, as shown in Fig. 3, was created from the defined configuration management model presented in the final design phase [5]. The entire GF manifold is discretized by the PIPE289 element (Fig. 3(a)), and the SOLID185 (Fig. 3(b)) element is used in nonlinear analysis for typical subsections. The MASS21 element is applied for simplified inner supports and/or pipes depend on the specific cases. Since influence of imperfections is incorporated into design factors during analysis, the geometric and material imperfections in the GF manifold due to manufacturing and assembling are neglected.

2.3. Material properties

All of the manifold components are fabricated with the SS316 L. The

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[*] Corresponding author.
E-mail address: caocz@swip.ac.cn (C. Cao).

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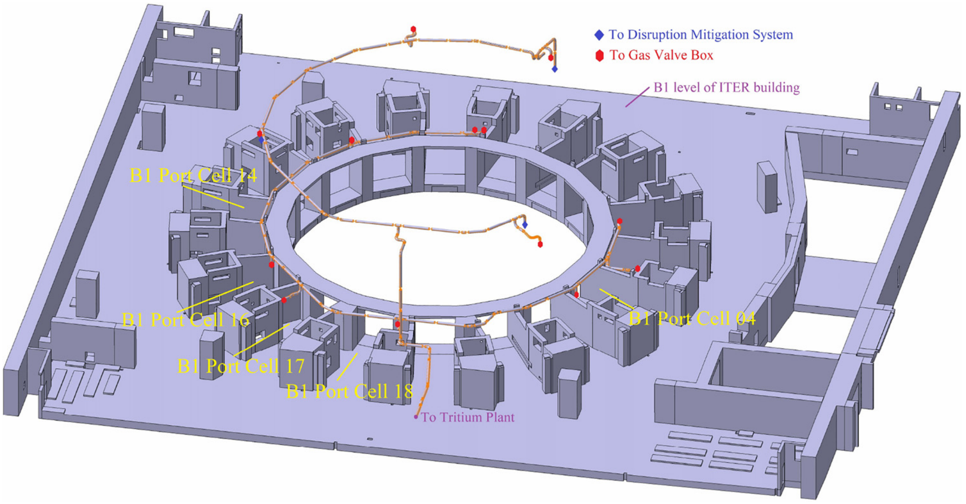

Fig. 1. Layout of GDS manifolds on the B1 level of the building.

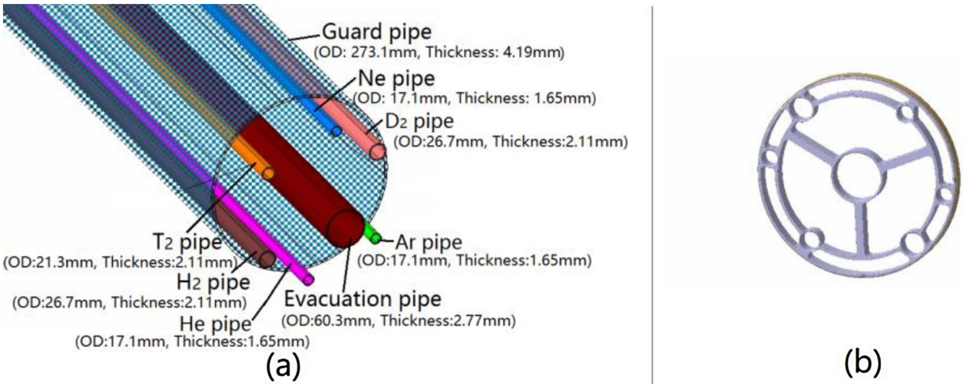

Fig. 2. Cross section of the GF manifold structure (a) and the internal support (b).

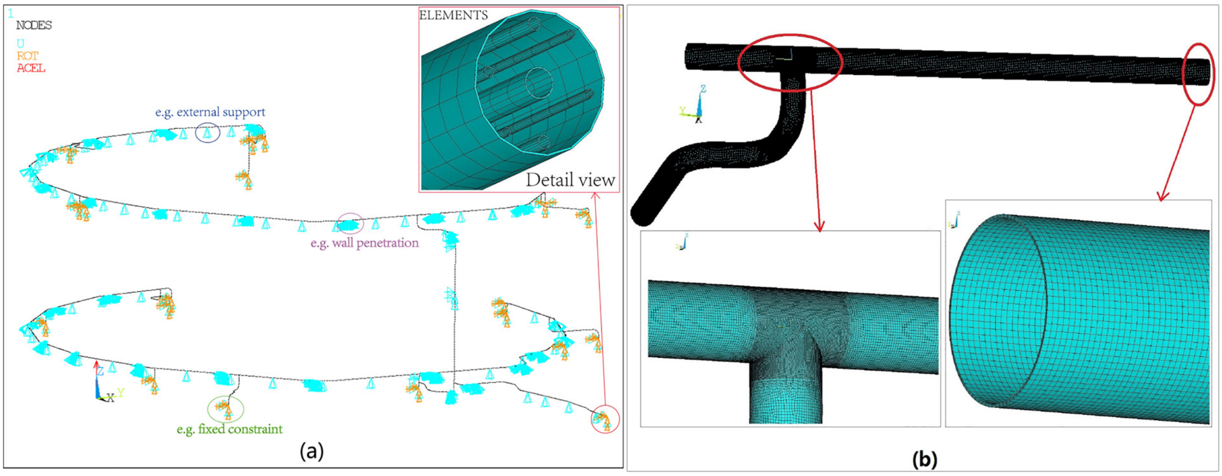

Fig. 3. (a) Entire (nodes) and detail (elements) of the GF manifold model, (b) Typical FE model (B1 Port Cell 17) for buckling analysis, including the entire model, detail of the T-unit and detail in thickness direction (three layers).

temperature-dependent material parameters are applied in analysis. The bilinear isotropic hardening is adopted to simulate the elastic-plastic properties. Since the SS316 L is a very ductile material with at least 35% elongation, the hardening tangent is calculated as $HT = \frac{\sigma_b - \sigma_s}{0.35}$. (MPa) ($\sigma_b$ is the tensile strength (MPa), σ_s is the yield strength (MPa)) to ensure a conservative design. The material properties are given in Table 1 (E is the elastic modulus (GPa), α is the coefficient of thermal expansion ($10^{-6}K^{-1}$), S_m allowable stress (MPa)

2.4. Boundary conditions

2.4.1. Elastic stress analysis

In the entire model (Fig. 3(a)), the displacement constraint perpendicular to the pipe axis on guard pipes represents external supports, and guard pipes are only fixed in cross-sectional plane and its axial displacement is allowed at locations of wall penetration (between two adjacent Port Cells). With defining a set of coupled degrees of freedom,