Coupled Thermo-Fluid-Solid Analysis of Engine Exhaust Manifold Considering Welding Residual Stresses

Xueyuan ZHANG*, Yu LUO* and Jianhua WANG*
*** School of Naval Architecture, Ocean and Civil Engineering, Shanghai Jiaotong University. Shanghai .200240, P. R. China**

KEY WORDS: (Welding residual stresses), (Optimization design), (Temperature field), (Modal analysis), (Coupled Thermo-Fluid-Solid analysis)

1. Introduction

The exhaust manifold mounted on the cylinder head of an engine collects a gas exhausted from an engine, and sends it to a catalyst converter. The exhaust manifold plays an important role in the performance of an engine system. Particularly, the efficiencies of emission and fuel consumption are closely related to the exhaust manifold. The exhaust manifold is under a thermal fatigue produced by increasing and decreasing temperature, which leads to a crack of the exhaust manifold. Through a great deal of efforts to increase the performance and to reduce the weight, automotive companies have tried to achieve a goal in optimal engine design.

In this paper, We investigates an exhaust manifold of the automobile engine. First, the welding residual stress distribution along the structure was predicted by themo-elastic-plastic(T-E-P) Finite Element Method (FEM). Then, in attempt to simulate the thermal boundary coefficients of the exhaust manifold wall under actual loading conditions, the internal flow fields are obtained using Computational Fluid Dynamics (CFD) software. The film heat transfer coefficient and the temperature of fluid boundaries were calculated. Furthermore, the thermal boundary conditions and welding residual stresses are mapped to the structural element surfaces of the exhaust manifold, based on commercial FE code ABAQUS. The temperature field of the exhaust manifold as well as the thermal stresses and distortions were simulated. Meanwhile, the welding residual stress effects on the modal analysis and thermal stress were also performed. It can simulate the loading condition of the exhaust manifold under the high temperature and make the coupled Thermo-Fluid-Solid analysis more accurately. A powerful technological guideline for assessing the reliability of the exhaust manifold and design of structural optimization can be revealed from current study.

2. Analysis methodology and data mapping

2.1 Analysis methodology

The flow and temperature field is solved using FLUENT(a CFD system) and resulting film heat transfer coefficient of fluid boundaries between solid and fluid and the ambient flow temperature is interpolated to the corresponding surface of a mesh generated for thermal-stress analysis. Then applies a simple boundary condition that consists of a constant ambient temperature and a constant film coefficient on the outer surface of the solid part of the pipe, The temperature distribution of the solid part is re-calculated and the thermal-stress analysis is done using ABAQUS.

2.2 Data mapping

One important issue here is how to convert the temperature field obtained in the CFD analysis to the input data for thermal stress analysis. The first consideration to be made is whether the same mesh should be used in both analyses. If the same mesh is used, the temperature values at the nodes can be used directly. If a different mesh is used in the thermal stress analysis, the temperature values at the nodes of the mesh be interpolated to the nodes of the mesh for thermal stress analysis. Thus some introduction of error is expected in the interpolation process. On the other hand, because the mesh can be different for CFD and structural analysis, a suitable mesh can be chosen for each analysis stage without affecting the other stage.

In the paper a different mesh is used, two interpolation methods can be considered to analyze the thermal stress field. The first method is to interpolate the turbulent film coefficient and corresponding ambient fluid temperature on the inner surface of the pipe. We call this method as surface mapping method. The second method is to interpolate the welding residual stress was predicted by T-E-P FEM to the nodes in the structural analysis mesh. We call this method as volume mapping method.

3. Practical exhaust manifold model

A more complicated model is used for additional investigation. The computational model to solve for flow field and associated thermal stress field. Fig. 1 shows the model of exhaust manifold. The mesh is created using Hypermesh preprocessor. The fluid part of the mesh

Table 1 Boundary conditions

Boundary conditions		
Domain	**Type**	**Value**
Inlet	Mass flow rate	302 kg/h; 870ºC
Outlet	Pressure outlet	25 kPa (gauge)
Substrate	Porous media ; walls as slip boundaries	C_2 =1.00106298294 (1/m); $1/\alpha$ =55798758.880 (1/m^2)

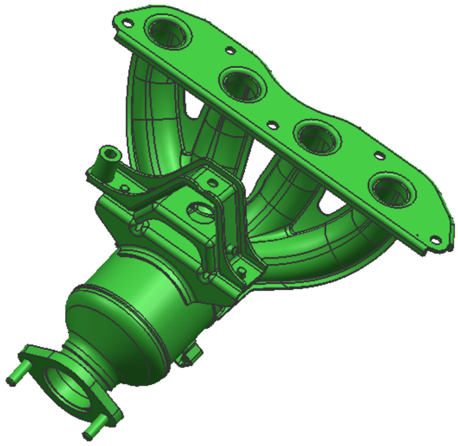


Fig. 1 Model of exhaust manifold

contains 921975 elements consisting of tetrahedral and hexahedral elements and the solid part contains 47566 hexahedrons.

3.1 Welding Analysis

The numerical analysis of temperature field, stress field and strain field during laser welding based on the T-E-P FEM of Abaqus were perform in this paper

3.2 The thermal analysis

As shown in Fig.2 and Fig.3 , the internal flow fields are obtained using Computational Fluid Dynamics (CFD)

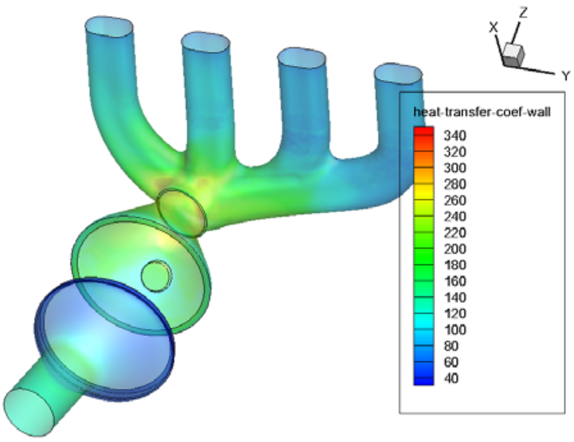


Fig. 2 The CFD result of exhaust manifold

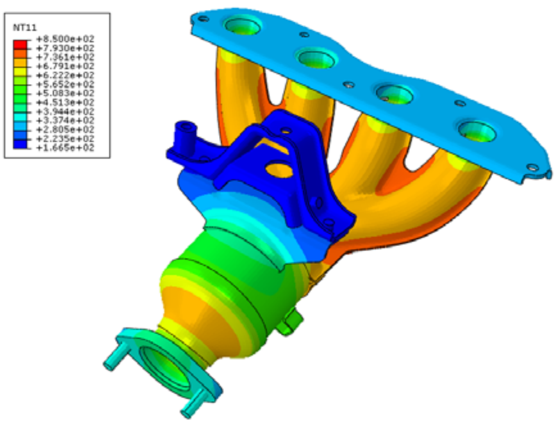


Fig. 3 The temperature distribution

software. The film heat transfer coefficient and the temperature of fluid boundaries were calculated.

3.3 The modal analysis

The modal analysis were computed with the thermal conditions presented previously in this paper. The results list in Table 2

Case 1: Considering Welding Residual Stresses

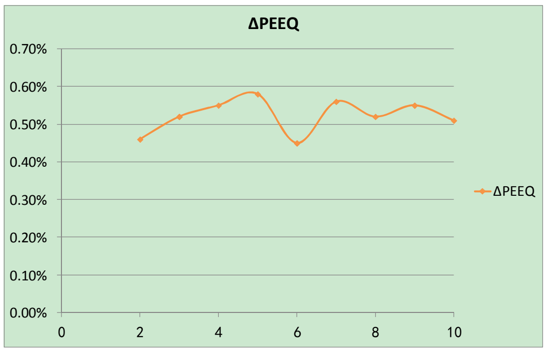
Case 2: Neglecting Welding Residual Stresses

Table 2 The modal frequency (Hz)

Mode No	1	2	3	4	5
Case 1	254	489	636	842	907
Case 2	245	468	568	714	750

3.4 The thermo-mechanical analysis.

The initial temperature was set to 20°C. Five thermal



cycles were computed. Evolution of ΔPEEQ over the

thermal cycles in the exhaust line, The ΔPEEQ in the

manifold after 5 thermal cycles is still below 1%. So The manifold will be durable

4. Conclusion

Considering welding residual stress effects on the modal analysis and thermal stress were performed. It can simulate the loading condition of the exhaust manifold under the high temperature and make the coupled Thermo-Fluid-Solid analysis more accurately.

References

[1] A. Ying, M. Narula, R. Hunt, Y. Ando, I. Komada, Integrated thermo-fluid analysis towards helium flow path design for an ITER solid breeder blanket module, Fusion Eng. Des. 82 (2007) 2217–2225.

[2] Ishii, K., Nakada, M., Takahashi, S., Enomoto, M. and Konishi, Y. Evaluation of Thermal Fatigue Life on the Exhaust Manifold by Analyzing Restraint Ratio. Fista Congress, 2000, 6.

[3] Q.Y. Fan, A Research on coupled transient analysis of thermal flow and thermal stress, SAE Technical Paper 2005-1-0516