



Evaluation of temperature effect on modal analysis for exhaust manifold

H. Ashouri

Department of Mechanical Engineering, Yadegar-e-Imam Khomeini (RAH) Shahre-Rey Branch, Islamic Azad University, Tehran, Iran,
ashouri1394@gmail.com

ARTICLE INFO

Article history:

Received: 30 January 2020

Accepted: 20 May 2020

Keywords:

Exhaust manifolds

Finite element analysis

Cold and thermal modal analysis

ABSTRACT

The effect of the temperature on exhaust manifold modal analysis was investigated in this study. For doing this, Solidworks software was used to model the exhaust manifolds. Then the modal analysis was performed to get the natural frequencies in Abaqus software. Finally, the modal analysis that considers the temperature effect was done. The study of structural dynamics is essential for understanding and evaluating the performance of any engineering product. The determination of the dynamic characteristics of automotive structures has become an extremely important issue in the automobile industry. Modal Analysis is currently one of the key technologies in structural dynamics analysis. The temperature-dependent of material parameters was considered to increase the accuracy of finite element analysis (FEA) results. The results of FEA proved a very good agreement between temperature distribution and thermal analysis results, carried out in references. The frequency and vibration mode between cold modal and thermal modal were compared. The results showed that temperature has a great influence on the exhaust manifold mode and it is very valuable to product design. The results of the modal analysis proved that the maximum strain energy density and total strain energy exist in the confluence area. The results of the finite element analysis correspond with the experimental tests, carried out in references, and illustrate the exhaust manifold cracked in this region. The obtained FEA results show that gas pressure is effective on the modal analysis and must be considered in the modal analysis of exhaust manifold.



1) Introduction

The exhaust manifolds are mounted on the cylinder head of an engine collects gases exhausted from an engine, and send them to a catalyst converter. They play an important role in the performance of an engine system [1-3]. The exhaust manifold is close to the engine part in the automotive exhaust system because the cylinder discharge gas temperature can reach 800°C above, the tail gas heating effect is obvious. Because the thermal stress, that caused by tail gas heating can be as high as hundreds of mega Pascals; it can also lead to thermal fatigue and cause a structural fracture. Thus, detailed analysis and design are essential [2, 3].

The study of structural dynamics is essential for understanding and evaluating the performance of any engineering product. The determination of the dynamic characteristics of automotive structures has become an extremely important issue in the automobile industry [4].

Modal analysis is used to study the inherent dynamic characteristics of a system. Through modal analysis, we can obtain natural frequencies, modal shapes, parameters of modal damping. Natural frequency can show that the structure can produce resonance under some certain excitation frequency [5].

Also, it is important to understand the dynamic characteristics of the exhaust system to reduce the vibration transmitted from the engine to the cabin, through the exhaust system [6].

Exhaust systems generally exhibit nonlinear material characteristics due to the higher combustion temperature which complicates the design due to the weakening of the material with increasing temperature. The problem is further exacerbated by the different levels of expertise on the part of customizing and servicing the engine, which results in a change in operating conditions expectation and anticipated temperatures [7, 8].

Thermal stress generated from temperature will have an impact on structural bending and torsional rigidity, which leads to a decline in structural natural frequency. Also considering the increasing demands on comfort, it is easily realized that designing exhaust systems has become much more difficult [8].

Numerous papers have been presented on modal analysis and prediction of fatigue failure in exhaust manifolds. Effects of an exhaust manifold with different structures on the sound order distribution of exhaust noise based on the

one-dimensional plane wave theory did by Qiu et al. The isometric exhaust manifold and symmetric isometric exhaust manifolds can control the sound order distribution of the exhaust noise, and they are applicable for improving the sound quality in the future [9].

Rajadurai et al. did Modal Analysis for Exhaust Manifold in Hot Condition. The results of their study disclosed that heating causes a non-linear change in material physical properties. Generated thermal stress caused by tail gas heating and mechanical loading from pretension leads to a decline in the natural frequency of the hot end exhaust system [8]. Operational and Experimental Modal Analysis for an automotive exhaust system was performed by Iyer et al. A very good agreement between experimental and simulated results of the modal analysis was proved [10].

Sissa and colleagues investigated low and high cycle fatigue life estimation of turbocharged diesel engine exhaust manifolds. Their research revealed that vibrational loadings cannot be neglected for correctly estimating the fatigue life of the turbocharged diesel engine exhaust manifolds [1].

The analysis of the crack mechanism and estimate of a lifetime by the vibration measurement of the stainless exhaust manifold in firing condition was performed by Sangkim and Joonpark. Their research proved that the vibration level in a vehicle is different from the level in bench condition. By checking resonance frequency and vibration level, we could predict endurance lifetime [11].

Rezaei studied vibration analysis of exhaust manifold heat shield. The results of finite element analysis proved that two of the first resonance frequencies of heat shield are in the range of the engine speed and locations of heat shield cracks are at the maximum deflection positions [12].

Optimization of exhaust system hangers for reduction of vehicle cabin vibrations analyzed by Shojaeifard et al. Simulated results indicated that optimization of the locations has resulted in a significant decrease in hanger loads, significantly reducing the vibrations transmitted to the vehicle cabin and increasing the life of the rubber hangers [6].

Fatigue strength of motorcycle exhaust system considering vibrating and thermal stresses was predicted by Kuribara et al. Their research proved a high correlation between experimental

and simulated results of the fatigue strength of the exhaust system [7].

Wang and Jiang investigated fatigue life estimation of the front subframe of a passenger car based on the modal stress recovery method. The durability analysis showed that the fatigue life of the improved subframe was greatly increased from 48,500 km to 766,200 km, while the mass of the modified bracket was increased from 0.526 kg to 0.578 kg, meeting the design requirements [13].

The impact of temperature effect on exhaust manifold thermal modal analysis was examined by Zou et al. With temperature pre-stress and bolt pre-tightening force and the same boundary condition, the exhaust manifold thermal modal frequency is lower than the cold modal frequency of the same order and with the increase of order, the reduction is larger [14].

Joshi et al. studied failure analysis and robust optimization of an exhaust manifold diffuser plate. Metallurgical failure analysis coupled with thermal fatigue analysis of the component concluded that thermal fatigue is the root cause of the failure [15].

Evaluation of thermal barrier coating in low cycle fatigue life for exhaust manifold was conducted by Ashouri. The results of low cycle fatigue proved that the number of cycles of failure for coated exhaust manifold is approximately in the order 2-fold longer than the results obtained from the uncoated exhaust manifolds [16].

Thermo-mechanical fatigue simulation of manifolds was studied by Ashouri. The numerical results showed that the temperature and thermal stresses have the most critical values at the confluence region of the exhaust manifolds. This area was under cyclic tensile and compressive stress and then is under low cycle fatigue [17].

According to the introduction, Temperature has a great influence on material mechanical properties, so it is necessary to take the influence of the temperature pre-stress on exhaust manifold vibration characteristics into account. Heating causes the nonlinear change of material physical property and generate thermal stress, the combined effects of both make the structure's natural frequency decline after heating. Thus, in the exhaust manifold design and evaluation, the effect of temperature on material mechanical properties should be taken into account. Thus, this article aims to evaluate

of temperature effect on modal analysis for the exhaust manifold. For doing this, Solidworks software was used to model the exhaust manifolds.

Then the modal analysis was performed to get the natural frequencies in Abaqus software. Finally, the modal analysis that considers the temperature effect was done. It should be noted that using time-dependent material properties would increase the accuracy of FEA results [8, 14]. Therefore, the effect of time-dependent properties for exhaust manifold is also considered in this work. It is worth noting that, the strain energy density and total strain energy distribution is investigated. Strain energy density is an appropriate criterion for predicting failure points in parts. The total strain energy predicts the failure point of the exhaust manifold in its first natural frequency. Pressure force exerted on the inner surface of the exhaust pipe wall is also taken into account.

2) Material behavioral model

In this study, the gray cast iron alloy of Silicon-Manganese has been used to simulate the thermo-mechanical behavior. The alloy is known as EN-JGL-250 gray cast iron which is applied in exhaust manifolds [16].

Heat transfer in engine exhaust manifolds is governed by three effects: conduction through the metal, convection from the hot exhaust gases, and radiative exchange between different parts of the metal surface [18, 19].

Heat transfer by conduction per unit area per unit time, in the steady situation is given by Fourier law [18]:

$$\dot{q} = -k\Delta T \quad (1)$$

The differential equation of time-dependent heat flow is given in polar coordinate by [20]:

$$\frac{1}{r} \frac{\partial}{\partial r} \left(kr \frac{\partial T}{\partial r} \right) + \frac{1}{r^2} \frac{\partial}{\partial \theta} \left(kr \frac{\partial T}{\partial \theta} \right) + \frac{\partial}{\partial \theta} \left(k \frac{\partial T}{\partial z} \right) = \frac{\rho c}{k} \frac{\partial T}{\partial t} \quad (2)$$

Heat loss due to thermal radiation between the manifold surface and environment is modeled by the standard Stefan-Boltzmann relation [18]:

$$\dot{q} = \varepsilon \sigma (T_g^4 - T_a^4) \quad (3)$$

Heat convection from the exhaust gas to the manifold wall is mainly due to forced convection

and is strongly dependent on the gas flow dynamics and the manifold geometry. These conditions can be mathematically expressed as follow [20]:

$$k \frac{\partial T}{\partial n} = h(T_g - T_a) \quad (4)$$

Chirchil and Chu law is used to consider heat convection from manifold surface to ambient air, the equation of which is following [21]:

$$Nu = \left\{ 0.6 + \frac{0.387Ra^{\frac{1}{6}}}{\left[1 + \left(\frac{0.599}{Pr} \right)^{\frac{9}{16}} \right]^{\frac{8}{27}}} \right\}^2 \quad (5)$$

3) Modal analysis theory

Vibration is an inevitable old problem for mechanical structures. Modal analysis is the study of the natural frequency and main modes of the mechanical system. According to mode theory, the structure will typically be seen as a system constituted by the mass point, rigid body, and damper and discrete it as a finite number of elastic coupling rigid bodies. Therefore, an infinite multi-degree freedom system turns into a limited multi-degree freedom system.

When the linear time-invariant system requirements are met, the system general motion mathematical model can be expressed as [22]:

$$m\ddot{x} + c\dot{x} + kx = f(x) \quad (6)$$

The temperature and temperature gradient have a great influence on the stiffness matrix K , which will lead to the change in the structural dynamics' characteristics. Considering the temperature effects, stiffness matrix K is composed of two aspects:

$$K = K_T + K_\sigma \quad (7)$$

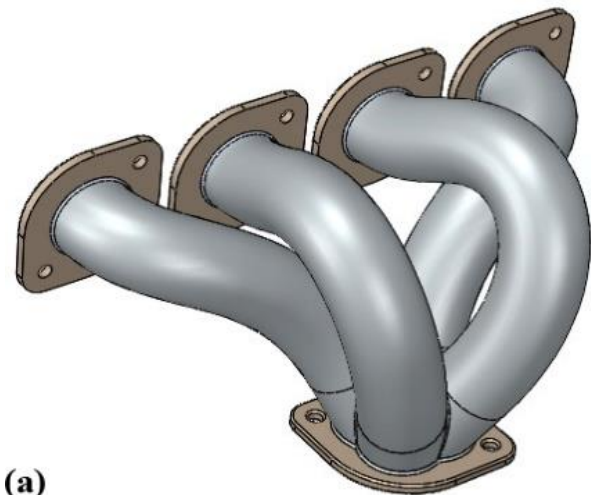
in which the first part K_T represents the thermal-related variation of material properties, including the elasticity and thermal expansivity and the second part K_σ is the stiffness caused by the structural thermal stress.

4) Finite element model and material properties

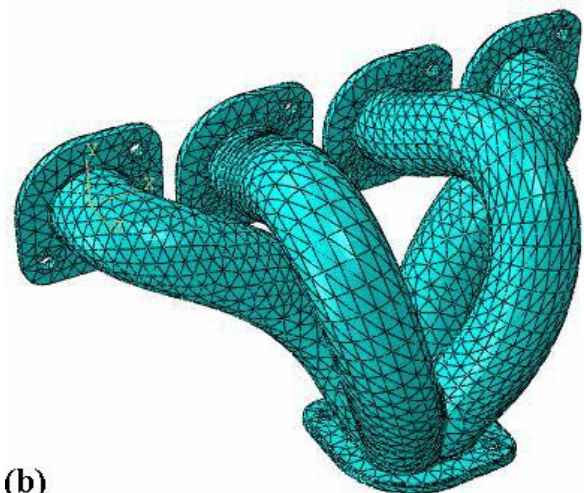
Hot components of engines had complex geometry and loading, and applying analytical

methods for the detection of natural frequencies, modal shapes, and parameters of modal damping in them is impossible. Many researchers have used the finite element method to obtain natural frequencies, modal shapes, and parameters of modal damping in geometrically complex components [8].

The exhaust manifold finite element model is shown in Figure. 1[16]. Exhaust manifolds consist of a four-tube exhaust manifold with four flanges, bolted with eight bolts to the engine cylinder head. The manifold is cast from gray iron with Young's modulus of 115 GPa, a Poisson's ratio of 0.26, and a coefficient of thermal expansion of 10×10^{-6} per °C. Exhaust manifolds are modeled with three-dimensional continuum elements. The model consists of 38989 nodes and 20093 elements (C3D10) for improving the accuracy and acceptability of the obtained results.



(a)



(b)

Figure 1: (a) The exhaust manifold generated by SolidWorks [16] and (b) Finite element model of the exhaust manifold

5) Analysis procedure

Temperature effect on exhaust manifold thermal modal analysis is as follows:

- 1- A modal analysis in cold condition includes linear material properties parameters.
- 2- Subject the exhaust manifolds to the steady-state operating temperature distribution.
- 3- Finally, a modal analysis in hot condition includes nonlinear material properties under maximum nodal temperature.

6) Results and Discussion

6.1) Cold modal Analysis

Modal analysis, namely free vibration analysis, is a linear analysis, which is a modern method to study the dynamic characteristics of structures. Modal is the natural vibration characteristics of the mechanical structure. Each mode has a specific natural frequency, damping ratio, and mode shape [14, 23, 24].

To avoid the damage of resonance to the mechanical structure before it works in reality, the modal analysis is necessary to judge whether there is a resonance. Based on the results of modal analysis, the stability of the device can be guaranteed by avoiding these frequencies or reducing the effect of excitation of these frequencies before the practical work.

To avoid the damage of resonance to the mechanical structure before it works in reality, the modal analysis is necessary to judge whether there is a resonance. Based on the results of modal analysis, the stability of the device can be guaranteed by avoiding these frequencies or reducing the effect of excitation of these frequencies before the practical work [4, 11].

In the cold modal analysis, cold modal analysis means the modal analysis with constant material properties parameters under room temperature [8]. It is assumed that the exhaust manifolds are securely fixed to a stiff and bulky engine cylinder head and catalyst, so the flange surfaces are constrained in the direction normal to the cylinder head and catalyst but are free to move in the two lateral directions to account for thermal expansion. Another boundary condition is the gas pressure of the exhaust manifolds. This pressure is applied as a mechanical load on the inner surface of the manifold tubes [16].

The first three order vibration shape of cold modal analysis are shown in Figure. 2. It can be seen that the first three natural frequencies of the exhaust manifolds are 1014.5, 1219.4, and 1276.4 Hz respectively.

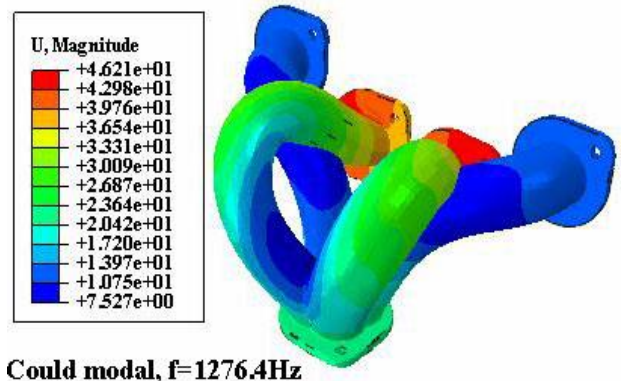
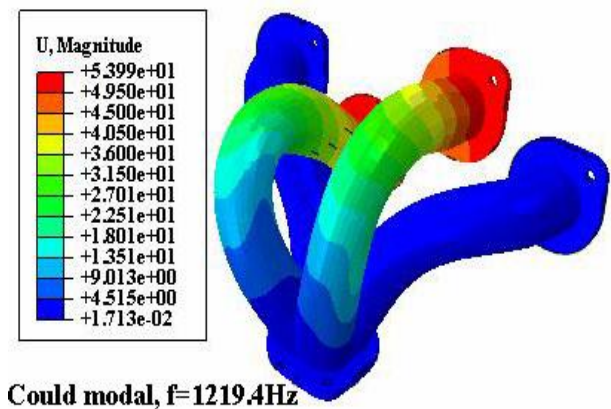
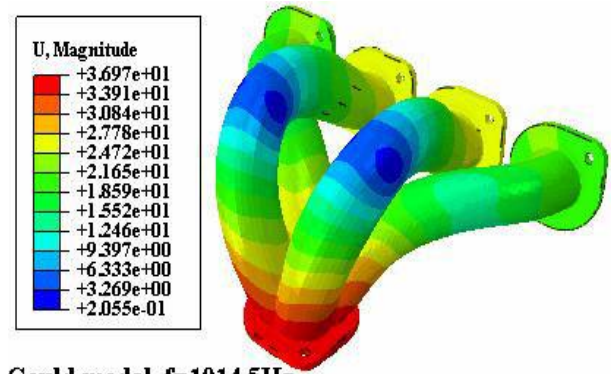


Figure. 2: The first three order vibration shape of cold modal

6.2) Thermal Analysis

The thermal analysis goal is the evaluation of temperature distribution in exhaust manifolds. The ability to accurately predict the metal temperature of the exhaust manifold is very important for a robust/durable design of the exhaust manifold. The ability to accurately predict the metal temperature of the exhaust manifold is very important for a robust/durable design of the exhaust manifold. The thermal analysis includes the simulation of working conditions in steady and transient states. In these conditions, exhaust manifolds are subject

to thermal exchange phenomena as conduction, convection, radiation [16, 17].

The manifolds are cast from gray cast iron with thermal conductivity of 48 W/mm°C, a density of 7200 kg/m³, and specific heat of 460 J/kg°C. The manifolds begin the analysis with an initial temperature of 20°C. The Stefan Boltzmann constant is taken as 5.669×10⁻¹⁴ W/mm²K⁴ and absolute zero is set at 273.15°C below zero. The surface emissivity of gray cast iron is taken as a constant value of 0.77. The hot exhaust gases create a heat flux applied to the interior tube surfaces. In this article, this effect is modeled using a surface-based film condition, with a constant temperature of 816°C and a film condition of 500×10⁻⁶ W/mm²°C.

A temperature boundary condition of 355°C is applied at the flange surfaces attached to the cylinder head, and a temperature boundary condition of 122°C is applied at the flange surfaces attached to the exhaust [16]. In this analysis, one thermal cycle is applied to obtain a steady-state thermal cycle. Each thermal cycle involves two steps: heating the exhaust manifold to the maximum operating temperature and cooling it to the minimum operating temperature. The temperature distribution when the exhaust manifold is heated to its peak value is shown in Figure 3.

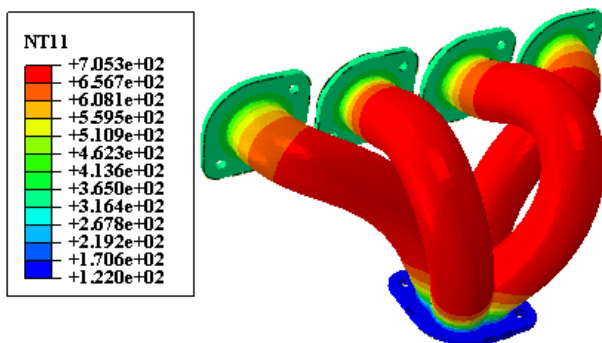


Figure 3: The temperature distribution in the exhaust manifold

Contour results of the temperature distribution in the exhaust manifolds carried out in references is shown in Figure 4. The review of Figures 3 and 4 reveals a very good agreement between temperature distribution and thermal analysis results, carried out in references. Contour results of the temperature distribution in the exhaust manifold considering temperature-independent material properties are shown in Figure 5. As it can be seen from

Figures 3-5, temperature-dependent of material properties has a significant effect on the temperature distribution. Therefore, temperature-dependent of material properties must be considered in the thermal analysis of the exhaust manifold.

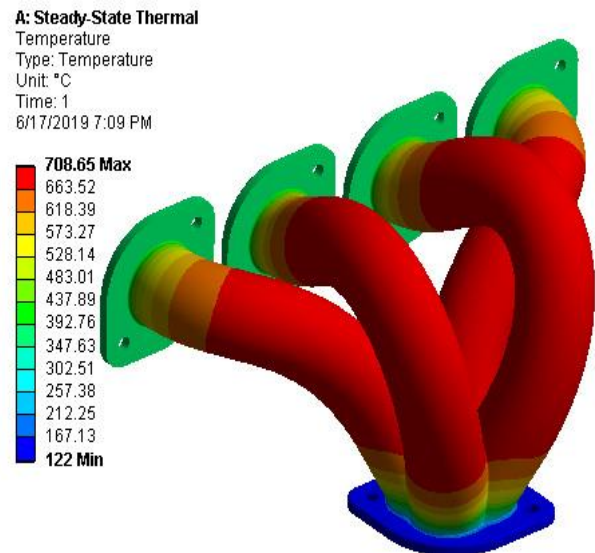


Figure 4: The thermal analysis of the exhaust manifold [16]

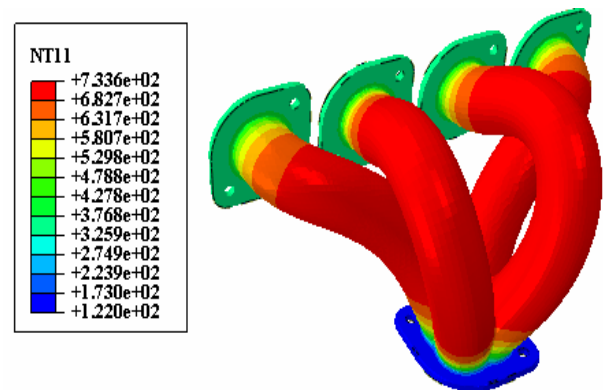


Figure 5: The thermal analysis of the exhaust manifold considering temperature-independent of material properties

6.3) Thermal modal Analysis

The temperature effect on structure stiffness is mainly from two aspects. First aspect: the heating up the temperature can change the material elastic modulus and lead to the initial stiffness matrix changes. Second aspect: The thermal stress caused by temperature gradients; the additional initial stress stiffness matrix is needed besides structure stiffness matrix. In the thermal modal, thermal modal analysis means modal analysis with temperature pre-stress and

with temperature-dependent material properties parameters [8].

Nodal temperatures calculated by the previous thermal analysis have been imported in the structural model as thermal loads. The first three order vibration shape of the thermal modal are shown in Figure 6. It can be seen that the first three natural frequencies of the exhaust manifold are 741.26, 897.44, and 951.57 Hz respectively.

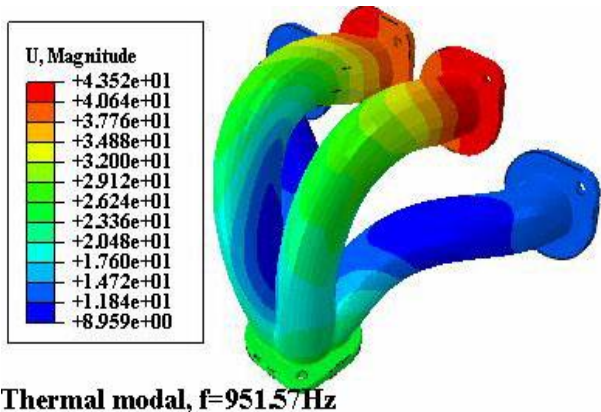
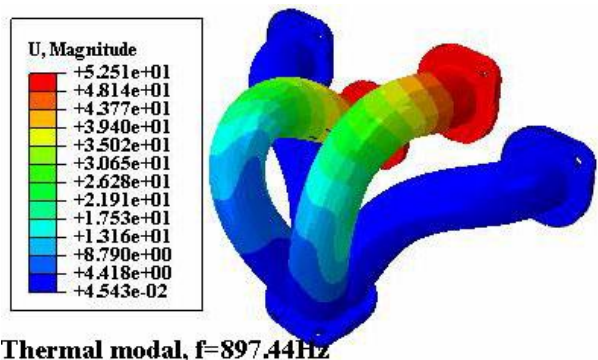
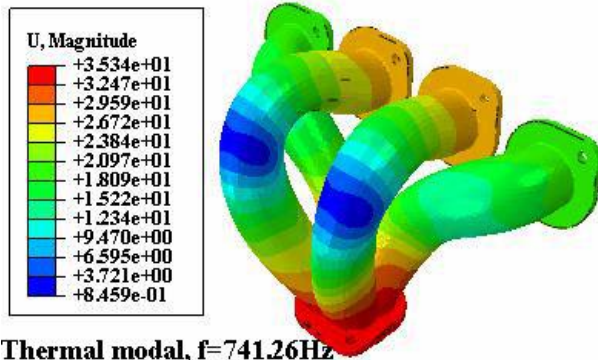


Figure 6: The first three order vibration shape of thermal modal

In the modal analysis, the low order vibration mode has a greater influence on the system structure. As can be seen from Figs 2 and 6, the first three modes of exhaust manifold solved by modal analysis do not overlap, which can

effectively avoid resonance phenomenon in operation.

Also, these natural frequencies are concentrated. The design process of the exhaust manifold should avoid these regions as much as possible to avoid resonance. With temperature pre-stress and the same boundary condition, the exhaust manifold thermal modal frequency is lower than the cold modal frequency of the same order. The influence of temperature on every modal frequency is different, but the total effect is lowering. It is correspondence to the results of a source [8].

The temperature reduces the material stiffness and uneven temperature distribution lead to material nonlinearity; on the other hand, the thermal stress that the temperature generated can be seen as pre-stress and will reduce the structure's bending and torsional stiffness, therefore, the structure natural frequency will be lower under the temperature pre-stress [8].

Through the above modal analysis, it can be seen that vibration shapes of cold modal (room temperature) and thermal modal are mainly bent. Therefore, the bend deformation is the most important vibration mode.

When the frequency of vibration is closed to the natural frequency of vibration in its practical works, the phenomenon of resonance will occur. The exhaust manifold is mainly motivated by the road and engine, generally, the road incentive is about 30 Hz and the engine incentive is more than 200 Hz, so the design frequency of the exhaust manifold should be greater than 200 Hz [6]. It can be seen by analyzing the results that the lowest order natural frequency of thermal modal analysis is 730.82 Hz and the cold modal's lowest natural frequency is 1007.8 Hz, both meet the requirements to avoid the resonance between the exhaust manifold and the engine or other parts.

It is worth noting that, the strain energy density distribution in the exhaust manifold is investigated. This energy represents the most probable failure point. The strain energy density is called SENER in Abaqus software. This parameter is an appropriate criterion for predicting failure points in parts. Strain energy density in the exhaust manifold predicts the critical points for failure as shown in Figure 7.

Another important variable in determining the failure point is the total strain energy. The total strain energy is called ELSE in Abaqus software. This variable predicts the failure point of the exhaust manifold in its first natural frequency as

shown in Figure 8. As it can be seen from Figures 7 and 8, SENER and ELSE parameters are maximized in the confluence area. Therefore, this region is a critical area and fatigue cracks will appear in this region.

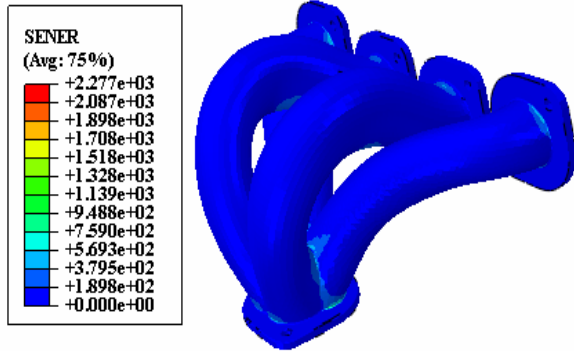


Figure 7: The strain energy density distribution in the exhaust manifold

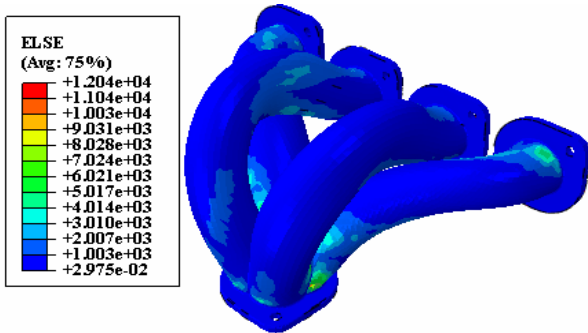


Figure 8: The total strain energy distribution in exhaust manifold in its first natural frequency

As it has been observed in most thermal shock test, the exhaust manifold is broken like Figure 9. The review of Figures. 7-9 reveals that the results of a modal analysis are corresponded with experimental tests carried out in references, and illustrate the exhaust manifolds cracked in this region.



Figure 9: The cracked exhaust manifold [25]

Gas pressure is effective on modal analysis. The first three natural frequencies of exhaust manifold by two methods are shown in Table 1. Comparing the natural frequencies of different methods, the influence of gas pressure on the natural frequencies of the exhaust manifold is very obvious. With gas pressure and the same boundary condition, the exhaust manifold thermal modal frequency is higher than the thermal modal frequency of the same order without gas pressure. It can be seen that the effect of gas pressure is significant. Thus, gas pressure must be considered in the modal analysis of the exhaust manifold.

Table 1: Natural frequencies of the exhaust manifold

Model number	Natural frequencies (Hz) with gas pressure	Natural frequencies (Hz) without gas pressure
1	741.26	730.82
2	897.44	888.14
3	951.57	939.14

7) Conclusion

In this study, a basic analysis process of the exhaust manifold cold modal and thermal modal analysis is studied. And the temperature pre-stress is applied on the exhaust manifold. Finite element analysis provides the accurate and reliable prediction of natural frequencies, modal shapes, and parameters of modal damping results in the exhaust manifold. The results of the modal analysis proved that heating causes the nonlinear change of material physical property and generate thermal stress, the combined effects of both make the structure's natural frequency decline after heating. By comparing the cold modal with thermal modal frequencies and vibration shapes, the results showed that the exhaust manifold thermal modal frequency is lower than the cold modal frequency of the same order. Thus, in the exhaust manifold design and evaluation, the effect of temperature on material mechanical properties should be taken into account. The temperature effects are directly proportional to the natural frequencies. By these effective results, dynamic characteristics of the system should be predicted with accuracy because of considering the real-life boundary conditions.

The result of FEA proved a very good agreement between temperature distribution and thermal analysis results, carried out in references. The results of the modal analysis showed that the maximum strain energy density and total strain energy exist in the confluence area. The results of the finite element analysis correspond with the experimental tests, carried out in references, and illustrate the exhaust manifold cracked in this region.

The obtained FEA results show that gas pressure is effective on the modal analysis and must be considered in the modal analysis of exhaust manifold. Computer-aided engineering plays an important role to find the weakness of an exhaust manifold layout at the early stage of engine development.

List of Symbols

\dot{q}	heat flux
k	thermal conductivity
ΔT	temperature difference
r	radius
ρ	density
c	specific heat
h	convective heat transfer coefficient
n	vertical direction
σ	standard Stefan–Boltzmann constant
T_a	air temperature
T_g	manifold temperature
Nu	Nusselt number
Ra	Rayleigh number
Pr	Prandtl number
M	Mass matrix
C	damping matrix
K	stiffness matrix
x	exhaust pipe vibration displacement vector
$f(t)$	exhaust pipe load vector

References

[1] S. Sissaa, M. Giacomina, R. Rosia, Low-Cycle Thermal Fatigue and High-Cycle Vibration Fatigue Life Estimation of a Diesel Engine Exhaust Manifold, *Journal of Procedia Engineering*, Vol. 74, pp. 105-112, 2014

[2] M. Chen, Y. Wang, W. Wu, J. Xin, Design of the Exhaust Manifold of a Turbo Charged Gasoline Engine Based on a Transient Thermal Mechanical Analysis Approach, *SAE Technical Paper No.2014-01-2882*, 2014

[3] L. Zhien, X. Wang Z. Yan, X. Li, Y. Xu, Study on the Unsteady Heat Transfer of Engine Exhaust Manifold Based on the Analysis Method of Serial, *SAE Technical Paper No.2014-01-1711*, 2014

[4] V. Sczibor, P. S. L. Alves, I. Bringhenti, Modal Parameter Estimation on Automotive Development, *SAE Technical Paper No.2012-36-0641*, 2012

[5] A. Ferrari, F. Paolicelli, Modal Analysis as a Design Tool for Dynamical Optimization of Common Rail Fuel Injection Systems, *SAE Technical Paper No. 2015-24-2467*, 2015

[6] M. H. Shojaeifard, S. Ebrahimi-Nejad, S. Kamarkhan, Optimization of Exhaust System Hangers for Reduction of vehicle Cabin Vibrations, *International Journal of Automotive Engineering*, Vol.7, pp. 2314-2325, 2017

[7] H. Kuribara, H. Horikawa, T. Teraguchi, T. Nagata, D. Kitamura, Prediction of Fatigue Strength of Motorcycle Exhaust System Considering Vibrating and Thermal Stresses, *SAE Technical Paper No. 2015-32-0739*, 2014

[8] S. Rajadurai, M. Guru Prasad, R. Kavin, M. Sundaravadivelu, Modal Analysis for Exhaust Manifold in Hot Condition, Is There a Need? *SAE Technical Paper No.2014-28-0036* Published 04/28/2014, 2014

[9] S. Qiu, Z.C Yuan, R.X. Fan, and J. Liu, Effects of exhaust manifold with different structures on sound order distribution in the exhaust system of a four-cylinder engine, *Journal of Applied Acoustics*, Vol.145, pp. 176–183, 2019

[10]G. Iyer, S. Mohan, N. Rao, Evaluation of Dynamic Characteristics of an Automotive Exhaust System using Operational Modal Analysis (OMA) and Experimental modal analysis (EMA), *SAE Technical Paper No.2013-01-2903*, 2013

[11] H. Sangkim, S. Joonpark, The Analysis of Crack Mechanism and Estimate of Lifetime by the Vibration Measurement of Stainless Exhaust Manifold in Firing Condition, *SAE Technical Paper No.2013-01-2643*, 2013

[12] M. Rezaei, Experimental and finite element vibrational analysis of exhaust manifold heat shield, *Journal of Engine Research*, Vol. 26, pp. 41-48, 2012

[13] D. Wang, R. Jiang, Sae, Fatigue Life Estimation of Front Subframe of a Passenger Car Based on Modal Stress Recovery Method, *SAE Technical Paper No.2015-01-0547*, 2015

[14] B. Zou, Y. Hu, Z. Liu, F. Yan, C. Wang, The impact of temperature effect on exhaust

manifold thermal modal analysis, Research journal of applied sciences, engineering and technology, Vol. 6, No. 15, pp. 2824-2829, 2013

[15] B. Joshi, H.R Shih, failure analysis and robust optimization of an exhaust manifold diffuser plate, Journal of failure analysis and Prevention. <https://doi.org/10.1007/s11668-018-0459-8>, 2018

[16] H. Ashouri, Evaluation of thermal barrier coating in low cycle fatigue for exhaust manifold, Journal of Simulation & Analysis of Novel Technologies in Mechanical Engineering, Vol. 11, 2019, No. 2, pp. 59-66, 2019

[17] H. Ashouri, Thermo-mechanical fatigue simulation of exhaust manifolds, Journal of Simulation & Analysis of Novel Technologies in Mechanical Engineering, Vol. 11, 2018, No. 2, pp. 59-66, 2018

[18] X. Li, W. Wang, X. Zou, Z. Zhang, W. Zhang, S. Zhang, T. Chen, Y. Cao, Y. Chen, Simulation and Test Research for Integrated Exhaust Manifold and Hot End Durability, SAE Technical Paper No. 2017-01-2432, 2017

[19] J.B. Heywood, Internal combustion engine fundamentals, McGraw-Hill press, 1998

[20] P.A. Konstantinidis, G.C. Koltsakis A. M. Stamatelos, Transient heat transfer modelling in automotive exhaust systems, Part C : Journal of mechanical engineering science, Vol. 211, pp. 1-15, 1997

[21] Y. He, P. Battiston, A. Alkidas, Thermal Studies in the Exhaust Manifold of a Turbocharged V6 Diesel Engine Operating Under Steady-State Conditions, SAE Technical Paper No.2006-01-0688, 2006

[22] W. T. Thomson, M. D. Dahleh, Theory of vibration with application, Pearson Press, 1997

[23] C. K. Takaemori, Operational modal analysis using durability test data, SAE Technical Paper No. 2016-36-0430, 2016

[24] S. P. Deshpande, P. Saha, A Modal Study of Damping Treatments to Improve Low Frequency Sound Transmission Loss of a Structure, SAE Technical Paper No. 2017-01-1852, 2017

[25] A. Londhe and V. Yadav, "Thermo-structural Strength Analysis for Failure Prediction and Concern Resolution of an Exhaust Manifold," CAE, R&D, Mahindra and Mahindra Ltd, Automotive Sector, Nasik, India, 2007



فصلنامه علمی تحقیقات موتور

تارنمای فصلنامه: www.engineersearch.ir



ارزیابی اثر گرما بر تحلیل ارتعاشی در چندراهه دود

حجت عاشوری

دانشکده مهندسی مکانیک، واحد یادگار امام خمینی (ره) شهرری، دانشگاه آزاد اسلامی، تهران، ایران، ashouri1394@gmail.com

چکیده

در این پژوهش اثر گرما بر تحلیل ارتعاشی چندراهه دود بررسی شده است. برای این منظور، ابتدا از نرم افزار سالیدور کس به منظور مدلسازی چندراهه دود استفاده شده است. سپس از نرم افزار آباکوس به منظور تعیین بسامدهای طبیعی استفاده شده است. در نهایت، اثر دما مطالعه شد. بررسی دینامیک یک سازه جهت مطالعه و ارزیابی هر محصول مهندسی لازم است. تعیین مشخصات دینامیکی ساختارهای مختلف خودرو موضوعی بسیار مهم در صنعت خودرو است. امروزه تحلیل ارتعاشی یکی از روش های توسعه فناوری در تحلیل ساختارهای دینامیکی است. نتایج تحلیل اجزای محدود نشان داد که انطباق بسیار مناسبی بین توزیع دما و نتایج تحلیل گرمائی انجام شده در منابع وجود دارد. فرکانس و شکل ارتعاش در تحلیل ارتعاشی در شرایط سرد و گرم مقایسه شد. نتایج نشان داد که دما اثر بسیار قابل ملاحظه ای بر ارتعاش منی فولد دود دارد که در طراحی آن بسیار حائز اهمیت است. نتایج تحلیل ارتعاشی ثابت کرد که حداکثر چگالی انرژی کرنش و مقدار انرژی کرنش در ناحیه همریختگاه رخ می دهد. نتایج تحلیل اجزای محدود با آزمون های تجربی انجام شده در منابع که چندراهه دود در این ناحیه دچار گسیختگی شده است، مطابقت دارد. نتایج تحلیل اجزای محدود بدست آمده نشان می دهد که فشار گاز بر تحلیل ارتعاشی مؤثر است و در تحلیل ارتعاشی چندراهه دود باید در نظر گرفته شود.

اطلاعات مقاله

تاریخچه مقاله:

دریافت: ۱۰ بهمن ۱۳۹۸

پذیرش: ۳۱ اردیبهشت ۱۳۹۹

کلیدواژه ها:

چندراهه دود

تحلیل اجزای محدود

تحلیل ارتعاشی در شرایط سرد و گرم



تمامی حقوق برای انجمن علمی موتور ایران محفوظ است.