

Assessment of Exhaust Manifold Sealing Performance Using Flange Distortion

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ABSTRACT

Gasket sealing performance of a manifold is traditionally characterized either by pressure distribution on flange face or line loads on gasket beads. These readings are sometimes susceptible to error due to complex contact algorithms or lack of reliable gasket data. In addition, they are difficult to correlate, particularly in the case of log-type manifolds. Here, a different approach for assessing gasket sealing performance of exhaust manifolds is presented based on overall manifold distortion under thermo-mechanical loading. Current technical paper describes the methodology used and presents a validation work.

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INTRODUCTION

Although there is a lot of research on thermo-mechanical fatigue behavior of exhaust manifolds [1,2,3,4], their sealing performance has not drawn as much attention. However, exhaust gas leakage is a commonly occurring problem that could result in failure of manifold gasket, loss of engine performance, etc. It can even affect catalyst emissions because of untreated emissions leak out and leaking of oxygen into the manifold due to waves in the exhaust system leading to an oxygen sensor offset [5].

In this study, assessment of gasket sealing performance of exhaust manifolds is presented as an alternative to the classical approaches based on gasket bead line load or pressure distribution on manifold flange face. This methodology is based on manifold distortion under thermo-mechanical loading. Distortion is characterized in terms of overall flatness of flanges that connect manifold to the cylinder head. Initial distortion before assembly is assumed to be zero notwithstanding manufacturing tolerances. Once manifold is assembled and heated up to elevated temperature, permanent plastic deformation takes place resulting in significant amount of residual stresses. When the manifold is disassembled from the cylinder head, it bends and takes a 'v-shape' due to residual stresses as shown in [figure 1](#). Individual distortion of each flange surface is negligible compared to overall distortion. Therefore, it is possible to fit a least-square-plane to flanges and to define upper and lower deviation from a perfectly flat surface. Difference between

these two gives us manifold distortion, analogous to 'flatness'.

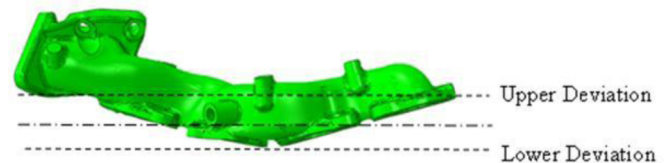


Figure 1. Distorted manifold shape after disassembly

It is usually considered that the larger the manifold distortion is, the more susceptible it is to exhaust gas leakage. Exhaust suppliers usually measure flange flatness in coordinate measuring machine as a part of their validation work. Therefore, this value can be used for the assessment of manifold sealing performance in CAE as well. This is particularly useful in the case of lack of reliable gasket data, such as loading/unloading characteristics of gasket beads or bead layout, or lack of correlation.

In this study, two different manifolds are modeled: Baseline & Modified manifold. Baseline manifold showed significant amount of leakage around the port closest to the turbo outlet during engine testing as show in [figure 2](#). Engine was stopped during dyno-testing because of torque loss due to leakage. Although two designs are similar in shape, modified design has different wall thicknesses on some areas to give a superior sealing performance to Baseline. It is the result of an iterative study based on the sealing performance criteria proposed in this study. Baseline Design was inspected

by means of a coordinate measuring machine (CMM) to make sure there is a correlation between measured distortion values and simulated ones, whereas superior sealing performance of the Modified manifold was proven by testing as well as simulation. Qualitative testing results are shown in [Table 1](#). The main focus of this paper will be describing the distortion as a measure of gasket sealing.



Figure 2. Gasket leakage around port IV, which is closest to turbo outlet

Table 1. Qualitative comparison of two manifold designs according to testing

Manifold Design	Gasket Sealing Performance
Baseline Design	Major leak with performance loss
Modified Design	Minor leak with no performance loss

FE MODEL

Commercial finite element package Abaqus® is used for this study. Finite element model includes manifold, bolts, gasket, turbo assembly and a representative cylinder head ([figure 3](#)). Small sliding contact behavior between each contact pair including bolt shanks and bolt holes are defined for accurate assessment of manifold distortion. Transient expansion of the manifold is obtained from 3D CFD analysis. A detailed material card including creep properties is used for Hi-Si-Mo manifold material.

Analyses are composed of a number of steps: Fixing of constraints, such as turbo brackets; clamping of bolts to the representative cylinder head; heating-up the manifold assembly; cooling it down (heating up/cooling down steps repeated for a number of times for a stable plastic region to develop); removing bolt-pretension; dismantling of manifold by removing contacts between bolts and manifold. These steps are shown in [figure 4](#). Once the analyses are completed and output files are created, nodal displacements are post-

processes to get flange distortion. For this purpose, a Matlab code is used to create least-square-plane and to determine corresponding deviations around each port.

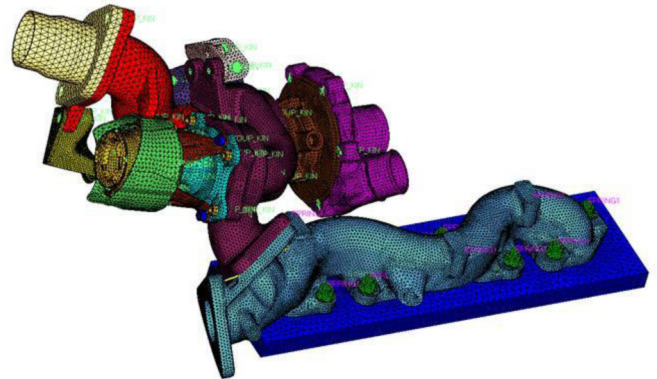


Figure 3. FE model of exhaust/turbo assembly

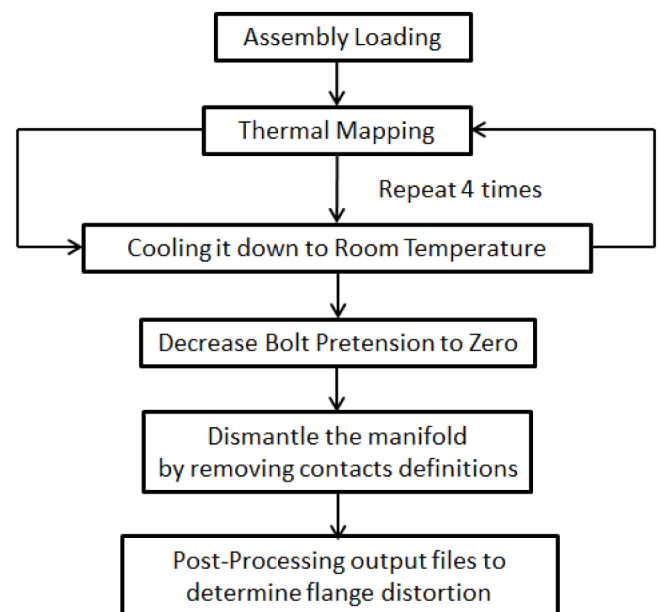


Figure 4. FE Analysis Steps

FLATNESS ANALYSIS

Flatness analyses for Baseline design was undertaken by the supplier with the failed manifold as shown in [figure 5](#). Two points at each exhaust port are taken as CMM datum measurement points. Datum points are set so that they are as far away from one another as possible to account for a wider surface on a flange as shown in [figure 6](#). A total of 8 datum points for 4 ports are used to construct least-square plane. 8 measuring points around each port are taken for the assessment of distortion; and distance between two closest parallel planes comprising all points, analogous to flatness, is used as a measure of distortion.