New Thermo Mechanical Analysis of Engine Valve using a Multi-Field Approach

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***Abstract* - Exhaust valve of an Internal Combustion engine is one of the most crucial parts. It is the main cause of most problems like preignition, burned valves etc. Design of the valve depends on many parameters like behavior of material at high temperature, fluid dynamics of exhaust gas, oxidization characteristics of valve material and exhaust gas, fatigue strength of valve material, configuration of the cylinder head, coolant flow and the shape of the exhaust port. The most important factor affecting the performance of a valve is its operating temperature. The three-dimensional geometries of the cylinder head and the water jacket were modeled by means of a computer-aided engineering tool. Commercial finite element and computational fluid dynamics codes were used to compute details of mechanical stress in the head and flow details in the cylinder and cooling jacket, respectively. To analyze the valve ANSYS is used as the tool. Thermal and structural analyses are performed on the valve. The results were in good agreement with experimental data. The results show high stresses at the valve bridge. Cylinder head temperatures and comparison of output power with high stress measurements, often exceeding the elastic limit, were found at the valve bridge.**

***IndexTerms* - Thermo mechanical, Engine cooling, Exhaust valve, Temperature, Heat transfer.**

I. INTRODUCTION

The valves used in internal combustion engines are of the three types;

- Poppet or mushroom valve;
- Rotary valve;
- Sleeve valve.

Out of these three valves, poppet valve is very frequently used. It consists of head, face and stem. The traditional process of design and development was time-consuming, and it was difficult to build physical prototypes during the early stages of the design. The construction and testing of many prototypes is often required to meet a stringent design requirement.

Mushroom valve consists of a head and a stem. It possesses certain advantages over the other valve types because of which it is extensively used in the automotive engines. The advantages are;

- Simplicity of construction
- Self-centering.
- Free to rotate about the stem to the new position.
- Maintenance of sealing efficiency is relatively easier.

The Finite Element Analysis methodology (FEA) assists engineers in predicting the best method for heat removal prior to building the first prototype, by calculating the temperature and stress distribution of each component. Therefore, Finite Element Analysis (FEA) is considered one of the most powerful computer-aided design tools for engineers. In the process of an engineering analysis, a theoretical and numerical model is the starting point for researchers to develop or design an engineering system.

II. EXPERIMENTAL SET-UP AND MATERIAL SELECTION

To provide the necessary information for calculations, an engine was installed on the dynamometer test. Four temperature probes were used on the outside surface of the cylinder head. The mean temperature reached 363.5 K, which will be used in the outside boundary condition of the cylinder head calculation.

Validation of the model has been achieved via calculation of the structural component temperatures in a 4-valve gas engine under firing conditions in dynamometer tests, and comparison of the calculation results with the corresponding, experimentally obtained data. The experimental temperature data were obtained via thermocouples applied to the cylinder head.

On account of operating conditions described above, the material for exhaust valve should have the following requirements.

- High strength and hardness to resist tensile loads and stem wear.

- High hot strength and hardness to combat head cupping and wear of seats.
- High fatigue and creep resistance.
- Adequate corrosion resistance.
- Least coefficient of thermal expansion to avoid excessive thermal stresses in the head.
- High thermal conductivity for better heat dissipation.

III. DESIGN AND MODELING

The assumptions made in modeling the process are given below:

- The valve material is considered as homogeneous and isotropic.
- The domain is considered as axis-symmetric.
- Inertia and body force effects are negligible during the analysis.
- The analysis is based on pure thermal loading and structural and thus only stress level due to the above said is done. This analysis does not calculate the life of the exhaust valve.
- The exhaust valve model used is of solid type.
- The thermal conductivity of the material used for the analysis is uniform throughout.
- The specific heat of the material used is constant throughout and does not change with temperature.
- Under normal operation, when the valve is properly seated at the ramp of the cam, stresses generated from seating are moderate. They can be very high when the valve train is improperly engineered so that the valve bounce occurs, or when the engine is over speeded or the valve lash is not properly set. In this analysis the stresses arising due to valve seating has been not taken into account assuming a normal operation.
- The distortion stresses in a valve arise due to misalignment of valve and seat. The valve head should deflect to accommodate to the seat, and this will cause bending stresses in the stem. Under all conditions, spring loads and gas pressures will be sufficient to bring the valve head into conformity with a mildly distorted seat.
- The engine considered for the analysis is a medium range engine (500 kW). It is assumed that it is water cooled.
- The heat generated inside the chamber is taken away by water chamber around cylinder liner and in the cylinder head.
- The temperature of water in the chamber is maintained at 50° C. Heat from the valve is lost through this water only.

The valve keeps popping up and down. The analysis is done for a stationary valve assuming that the fatigue life of the valve is very high and the stress arising due to that has been neglected.

IV. BOUNDARY CONDITIONS

Boundary Conditions are classified into two types as,

- Thermal boundary condition
- Stress boundary condition

A. Thermal boundary condition

In any thermal analysis, proper selection of boundary conditions is challenging, particularly when boundary conditions in the engine combustion chamber components may vary significantly, both in space and time. The boundary conditions for stress analysis are achieved from the results of thermal analysis and the suitable displacement boundary conditions of the cylinder head. In this analysis, only thermal and pressure loads from the combustion chamber were considered. The high-stressed regions were sought and evaluated accurately and closely.

To consider all boundary conditions, one of which was achieved in previous sections (combustion simulation), the convective heat transfer coefficient should be calculated for the following regions. The pressure load in producing stress in the cylinder head is not as important as thermal stress which is dominant.

B. Stress boundary condition

In order to decrease the complexity of the boundary conditions, interaction between the cylinder head, cylinder head gasket and cylinder block was not modeled. In fact, the cylinder head and the cylinder block were assumed to expand at the same rate for all points of contact between the cylinder block and cylinder head.

Another boundary condition is the pressure load which is applied to the combustion chamber. Maximum pressures of 13.07 MPa and 13.411 MPa for a gas engine and a diesel engine are used in this analysis, respectively. The boundary condition of the bolt is very significant. This simplification does not allow the cylinder head bolts to constrain the thermal expansion of the cylinder head. Therefore, thermal stresses are expected to be predictable. In an actual model, a pre-load is necessary in order to define how to tighten the bolt.

Therefore, a pre-load is applied to the cylinder head. In this analysis, it is assumed that the surface interface of the cylinder head and bolt move inward. There is no outward movement for this surface.

V. DISCUSSION AND RESULTS

A comparison of diesel engine thermal analysis results and natural gas engine. The temperature at the centre of any cylinder is high and decreases far away from the centre. This causes a high temperature gradient at the surface of the combustion chamber. This is due to the fact that far away from the centre, the cooling water flow rate is greater than at the centre of the fire deck, but it is assumed that the temperature in the water jacket is almost constant.

The temperature at the cylinder bridge is high (in the natural gas and diesel engines), and consequently the temperature gradient at this region remains high. The maximum temperature at the fire deck is 727.837 K in a natural gas engine and 616.227 K in a diesel engine (it is one of the reasons for the high stress of the natural gas engine).

The FEM predicts a large compressive strain and stress field at the valve bridge and at the valve seats on the foredeck of the cylinder head. These stresses are assumed primarily to be the result of the relatively large temperature differential existing at the liner interface.

A. Thermal analysis

Thermal analysis of the exhaust valve for different materials are carried out. The results of the two different exhaust valve materials are carried out was steady state thermal, the results for all the materials are almost same.

B. Structural analysis

Static structural analysis of the exhaust valve for different materials are carried out. The properties of different exhaust valve materials such as thermal expansion, young's modulus are given as input to the structural analysis.

VI. CONCLUSION

An investigation of stress and heat transfer by extensive solid work, FEM/CFD and thermal analysis selected cylinder heads (converted engine) is conducted in the present work to determine their critical areas and weak points for development and design. Based on the reported results, the following conclusions may be drawn:

- Maximum compressive stress is located at valve seats and at the valve bridge. Natural gas engine stress is about times higher than diesel engine stress. High stresses at the valve bridge, resulting from a constrained thermal expansion of the cylinder head, are generally compressive in those areas.
- The use of cast iron GG-30 in the production process instead of the existing material of a natural gas engine, cast iron GG25, leads to prevention of quick destructive fractures in the cylinder head and makes the assurance factor increase.
- Decrease of maximum compressive stress and high temperature in some critical areas, such as the valve bridge or valve seat, the water-cooling system or water jackets in the cylinder head, should be improved.

In this project thermal and structural analysis for two materials produces excellent result by treating the problem as coupled field analysis.

From the analysis results for both valve materials, it has been concluded that the displacement value is very less than the values of other material for the same thermal and structural loads.

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REFERENCES

[1] Spaniel, M., Macek, J., Divis, M. and Tichanek, R. ''Diesel engine head steady state analysis'', International Journal of Middle European Construction and Design of Cars, 2(3), pp. 34–41 (2003).

[2] Agarwal, A. and Assanis, N. ''Multi-dimensional modeling of natural gas ignition under compression ignition conditions using detailed chemistry'', International Journal of Science and Combustion, 163(1), pp. 177–210 (2001).

[3] M. H. Shojaefard, A. R. Noorpoor, M. Ghaffarpour, F. Mohammadi, "Analysis Heat Flow between Seat and Valve of ICE," American Journal of Applied Sciences 4 (9): 700-708, 2007ISSN 1546-9239© Science Publications 2007.

[4] Nurten Vardar, AhmetEkerim, "Investigation of Exhaust Valve Failure in Heavy – duty Diesel Engine," Gazi University Journal of ScienceGU J Sci23(4):493- 499 (2010)

[5] SingaiahGali, T.N Charyulu, "Diesel Engine Exhaust Valve Design, Analysis and Manufacturing Processes," Volume 2, Issue. 7, Aug 2012Indian Streams Research Journal

[6] T. T. Mon, M.M.Noor, K.Kadirgama, Rosli A.Bakar, M.F.Ramli, "Finite Element Analysis on Thermal Effect of the Vehicle Engine," Malaysian Technical Universities Conference on Engineering and Technology June 20-22, 2009, MS Garden, Kuantan, Pahang, Malaysia

[7] Chyuan. S, ''Finite element simulation of a twin-cam 16-valve cylinder structure'', International Journal of Finite Element in Analysis and Design, 35(3), pp. 199–212 (2000).

[8] Roelle, M.J., Shaver, G.M. and Gerdes, J.C. A multi-mode combustion model of SI and HCCI for mode transition control, in: Int. Conf. on Mech. Engineering, Anaheim, California, USA, 2004, pp. 329–336.
[9] Cranfield, A. Effects of diesel water emulsion combustion on diesel engine NOx emissions, Master's Thesis, Florida University, 1999.
[10] Trigui, N., Griaznov, V., Affes, H. and Smith, D. ''CFD based shape optimization of IC engine'', International Journal of Oil & Gas Science and Technology, 54, pp. 297–307 (1999).
[11] Reyes, A., Beginner's Guide to Solidworks, Schroff Development Corporation, Scherod Development Corporation (SDC) Publications, India, (2005).
[12] Chang, J., Guralp, O., Filipi, Z., Assanis, D., Kuo, T.W., Najt, P. and Rask, R. New heat transfer correlation for an HCCI engine derived from measurements of instantaneous surface heat flux, SAE paper 2004-01-2996, 2004.
[13] Depcik, Ch. and Assanis, D. A universal heat transfer correlation for intake and exhaust flows in a spark-ignition internal combustion engine, SAE paper 2002-01-0372, 2002.
[14] Pulkrabek, W.W., Engineering Fundamentals of Internal Combustion Engine, Prentice Hall, USA, (1997).