ISSN: 2350-0328

International Journal of Advanced Research in Science, Engineering and Technology

Vol. 3, Issue 7 , July 2016

Design and Analysis of a High-Pressure EGR Valve for a 4-Cylinder Diesel Engine

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ABSTRACT:The aim of this research work is to design a EGR Valve for a 4-Cylinder Diesel Engine. The EGR Valve of alloy steel and EGR valve casing of aluminum alloy is modelled in Autodesk Inventor and Analysis of same was done in the FEA module of the Autodesk Inventor. Structural analysis of EGR valve is carried out to study stress distribution, strain, deformation, etc for real world implementation. It is designed in a manner that the EGR valve will support different loading condition without failure. Basic approach is to reduce the mass of EGR valve which directly leads to reduce overall mass of the EGR system. High pressure EGR valve uses a poppet valve and have high tendency to fail under thermal and fatigue loading. The EGR valve is designed to sustain different pressure and thermal loading. In order to reduce deposition of soot particles over the surfaces of EGR valve, geometry of valve is properly designed to allow different mass flow rate of exhaust conveniently.

KEYWORDS:EGR valve, FEA, Autodesk Inventor, Deformation, Stress

I. INTRODUCTION

Exhaust Gas Recirculation is an mechanism which circulates the engine exhaust to inlet manifold upon the direction from Electric Control Module of the engine. It contains a EGR valve and a EGR cooler whose sole purpose is to transfer the cool exhaust gases to the Inlet of the engine. EGR is used in diesel engine for the reduction of NOx. Formation of nitrogen oxides at high temperature is well known in diesel engine. By cooling the exhaust gas through EGR cooler and transferring it to Inlet at low temperature, it reduces the overall combustion temperature and hence reduces the NOx formation. EGR valve regulates the flow of Exhaust Gas. Its objective is to start or to stop the flow of exhaust gas, control exhaust flow rate, divert flow, prevent back flow, control pressure, or relieving pressure. Poppet valve is used in High pressure EGR System. The purpose of EGR system is to precisely regulate EGR flow under variable working condition. EGR system also has to change flow for different conditions which may leads to compromising of engine performance. With the engine load varies, the significant amount of engine exhaust gas which must be metered into the intake manifold. This results in the EGR system working on a very thin line between good control of NOx and good engine performance. The performance of engine may affect if large amount of exhaust gas is metered. There may be a possibility of knocking in the engine and the exhaust emissions may not meet the required standards if much less EGR flows. The exhaust gas and fresh air mix in the intake manifold or boost pressure tube. The recirculated exhaust gas is added to the mix by an exhaust gas recirculation valve located on the engine. The recirculated exhaust gas reaches a temperature of approx. 400 °C to 600 °C. EGR valves must be securely sealed against the exhaust gas back pressure and the boost pressure. They must also be resistant to soiling, soot contamination and harmful condensates, which can lead to corrosion.

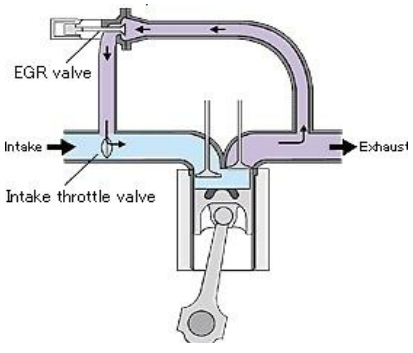

Fig-1, EGR Valve Mechanism

ISSN: 2350-0328

International Journal of Advanced Research in Science, Engineering and Technology

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II. DESIGN OF EGR VALVE

1. Size of valve port: ApVp = AV, Ap = Π/4 Dp², Diameter of valve port, Dp = 28 mm
2. Thickness of Valve Disc, t = kDp $\sqrt{p/\sigma b}$, Thickness of valve disc, t = 4.30 mm
3. Maximum lift of valve, h = Dp/4Cosα, Lift of valve, h = 10mm
4. Diameter of Valve stem, Ds = Dp/8 + 6.35 = 9.85 mm

It is quite larger, we optimize the diameter of stem to 6 mm.

S.no	Parameter	Dimension
1.	Diameter of valve port	28 mm
2.	Thickness of valve disc	4.30 mm
3.	Lift of valve	10 mm
4.	Diameter of Valve stem	6 mm

III. MATERIAL

The material should have enough strength to withstand all the loads acting on it in dynamic conditions. The material selection also depends on number of factors such as material properties, availability and the most important parameter is the cost. Alloy steel is selected for the material of EGR valve and Aluminum Alloy is chosen for the valve casing or body.

A. Material specification for Valve:

S.no	Property	Specification
1.	Mass Density	7.73 g/cm^3
2.	Yield Strength	250 MPa
3.	Ultimate Tensile Strength	400 MPa
4.	Young's Modulus	205 GPa
5.	Poisson's Ratio	0.3 ul
6.	Shear Modulus	78.8462 GPa

B. Material specification for Valve casing:

S.no	Property	Specification
1.	Mass Density	2.7 g/cm^3
2.	Yield Strength	275 MPa
3.	Ultimate Tensile Strength	310 MPa
4.	Young's Modulus	68.9 GPa
5.	Poisson's Ratio	0.33 ul
6.	Shear Modulus	25.9023 GPa

IV. MODELLING

The design of EGR valve for the 4-Cylinder Diesel Engine is modelled in Autodesk Inventor software. It involves creating of sketch in the two dimensional sketch module and then transferring it to three dimensional sketch module and by using extrude command, the two dimensional sketch is converted to solid model or part. of EGR valve for a Diesel Engine is modelled. The assumptions which are made while modeling the process are given below.

- The material is considered as homogenous and isotropic.
- The problem domain is considered as axis- symmetric.
- Inertia & body force effects are negligible during the analysis.

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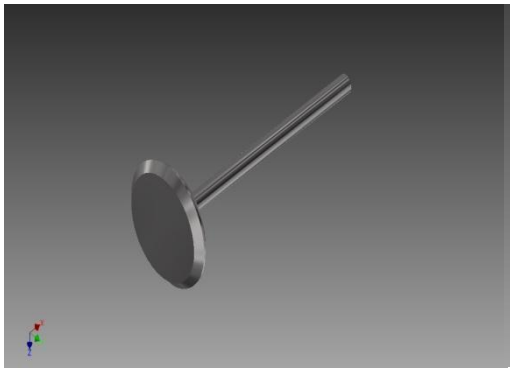
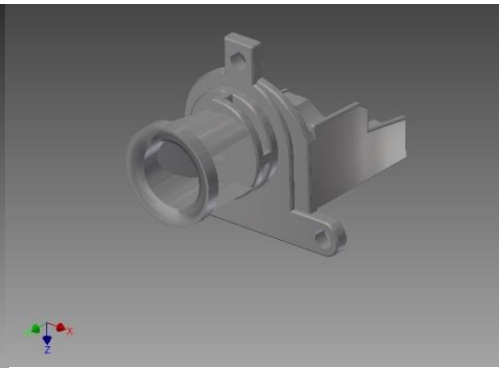

Fig-2, EGR ValveFig-3, EGR Casing

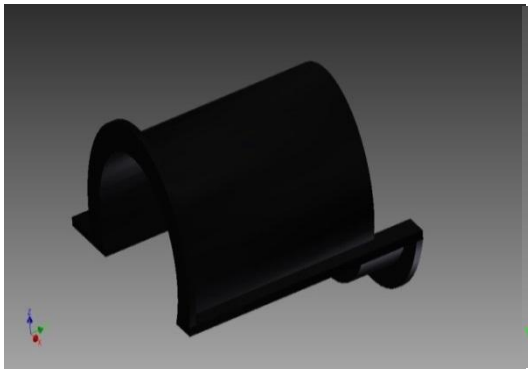
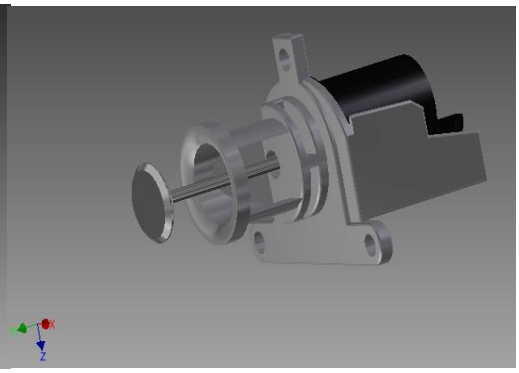

Fig-4, EGR Casing Cover view Fig-5, EGR Valve Assembly View

V. ANALYSIS

A structural analysis is performed over the disc when the loads & boundary conditions remain stationary & do not change over with the time. It is assumed that the load or field conditions are applied gradually, not suddenly. The system under analysis can be linear or nonlinear. Inertia and damping effects are ignored in structural analysis. Static analysis is used to determine displacements, stresses, etc. In structural analysis following matrices are solved [K][X]= [F], Where K is stiffness matrix, X is displacement matrix, & F is the force matrix.

A. **Meshing**

Meshing involves division of the entire of model into small pieces called elements. It is convenient to select the free mesh because the valve is circular in shape, so that shape of the object will not alter. To mesh the valve element type must be decided first. The numbers of elements after mesh are 11260 and the total numbers of nodes are 21950. Here, the description of element type is follows as:

S.no	Property	Specification
1.	Avg. Element Size (fraction of model diameter)	0.1
2.	Min. Element Size (fraction of avg. size)	0.2
3.	Grading Factor	1.5
4.	Max. Turn Angle	60 deg
5.	Create Curved Mesh Elements	No
6.	Use part based measure for Assembly mesh	Yes

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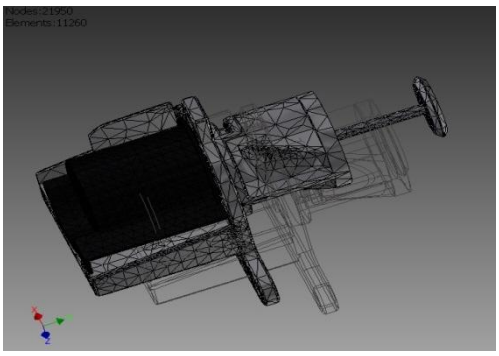

Fig-6, Meshed View of EGR Valve Assembly

B. **Pressure Applied**

A pressure of 0.2 Mpa is applied to the face of valve disc. Pressure is applied at normal to the surface of disc.

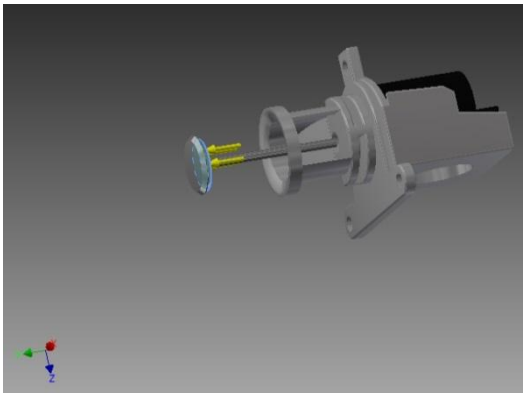

Fig-7, Pressure Applied

C. **Von Mises Stress**

The equivalent Von Mises Stress induced in the assembly under the action of applied pressure. The maximum stress induced on the valve stem is 6.92 Mpa. Red zone indicates the maximum stress area and blue zone indicates the area of minimum stress.

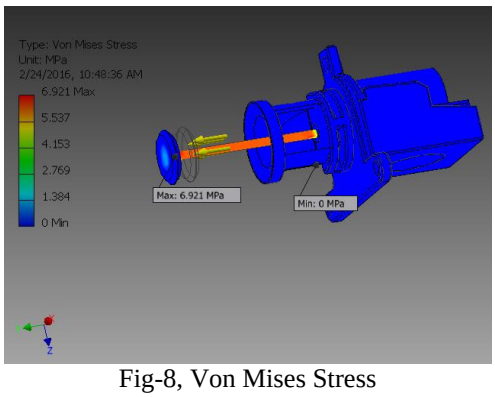

Fig-8, Von Mises Stress

D. **Displacement**

The Displacement induced in the assembly under the action of applied pressure. The maximum displacement induced on the valve disc is 0.006mm. Yellow zone indicates the maximum deformation area and blue zone indicates the area of minimum deformation.

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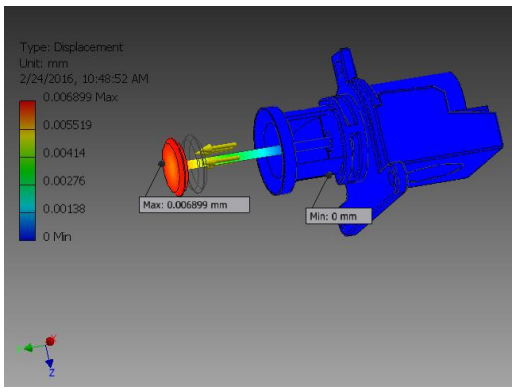

Fig-9, Deformation

E. **Safety Factor**

The safety factor for the assembly under the action of applied pressure. The maximum safety factor induced on the valve disc is 15.

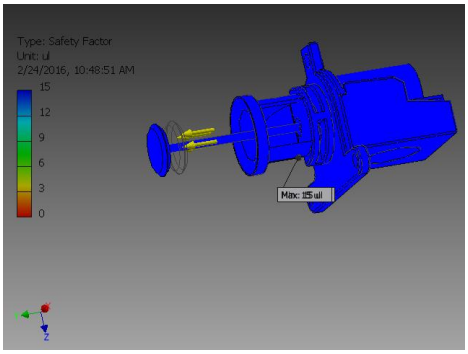

Fig-10, Factor of Safety

F. **Equivalent Strain**

The equivalent Strain induced in the assembly under the action of applied pressure. The maximum Strain induced on the valve stem is 0.0000910975. Red zone indicates the maximum Strain area and blue zone indicates the area of minimum Strain.

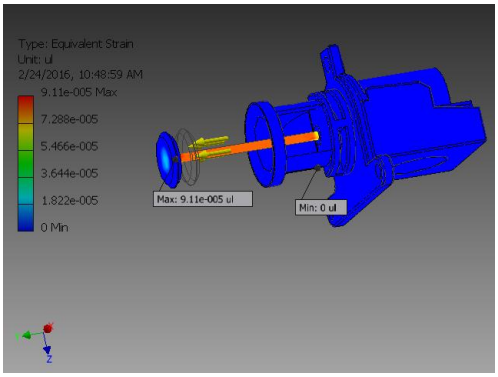

Fig-11, Equivalent Strain

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VI. CONCLUSION

The EGR valve is designed for the 4-Cylinder Diesel Engine. It is made up of Alloy steel which has enough strength to sustain under variable loading condition. The thickness of designed valve disc is 6 mm which is validated by the results of Von mises stress, Principal stress, Strain, Deformation and FOS (Factor of Safety). Hence the designed disc is safe.

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