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# DESIGN AND OPTIMIZATION OF INTAKE MANIFOLD IN A VOLKSWAGEN CAR

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**Abstract:** The objective of this work was to develop a new design of a high performance intake manifold through a combination of CAD and FEM. First a FEA model was done, which included a complete thermal and structural analysis of the new intake manifold and the contact area between the aluminum coupling, using the combined tools of CATIA, ANSYS WORKBENCH, MATHCAD. Then several composite prototypes were made where analyzed.

## 1. INTRODUCTION.

Due to the need of reaching the automotive industry as well as the real interest on innovating in the new materials field, this idea was developed in order to study the different possibilities available to build an intake manifold for the mentioned car.

Finite element method was used for simulations. Some composite material were previously characterized and added to ANSYS WORKBENCH 12.1 library. The material finally used was relatively simple to be included into this FEM software due to its mechanical behavior. Due to the epoxy thermo resin properties, its behavior is elastic and proportional until break. Main properties were modelized by means of MATHCAD so that was possible to include all of them in the FEM software.

After some calculations, a final geometry and coupling was decided and compared with the rest of suitable possibilities for this implementation, showing that the final cost is lower than the traditional one and observing a relative simplicity for the final manufacturing process.

## 2. EXPERIMENTAL

This study started with materials that were previously used by some prestigious brands, manufacturers of cars. Later on, the initiative came to develop the same materials but used in different way and, due to it, with a simpler and much cheaper manufacturing process.

An epoxy resin was chosen. Even having a high price in comparison with some other resins, the final composite material presents good mechanical properties such as high mechanical resistance and good flammability behavior. In the same way, the nylon and E-glass fiber laminated properties are very similar to the injected reinforced PA-66 with 33% of glass fiber so it can be concluded that the final material is much better for an isolated implementation like this one.

To start with the design, the engine and available space for it into the car was needed to be taken into account as for a normal car it was not wanted the fact of extracting the intake system out of the body shell. On the other hand, the engine itself has geometry not suitable to join 5 intake conducts with the same dimensions. The mentioned engine is shown in figure 1 so it is possible to verify the complexity of modeling an intake manifold respecting a similar dimension for all the runners so that the filling air and fuel mixture can adopt turbulence approximately equal for each cylinder.

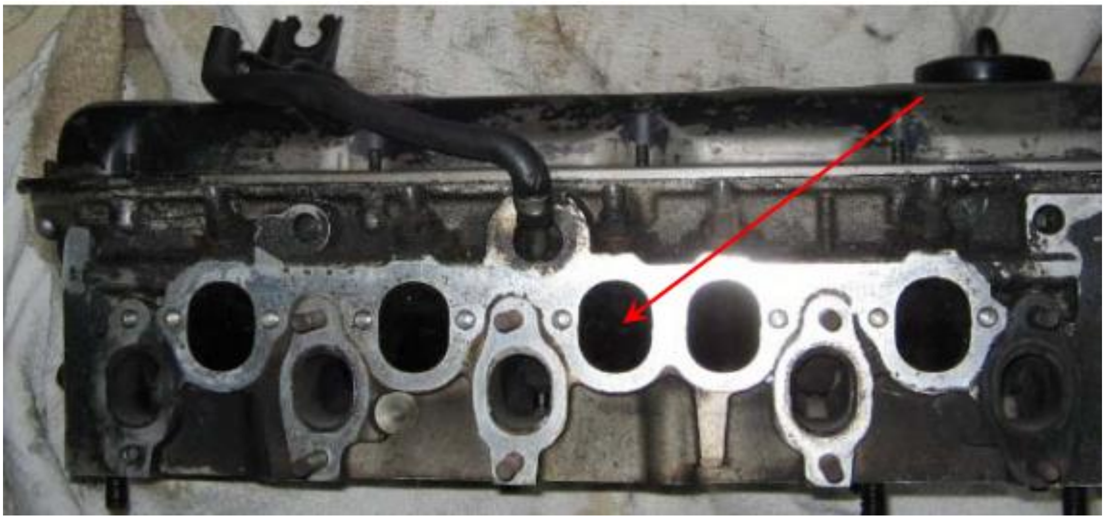

***Figure 1. Cylinder head geometry.***

Figure 2 depicts the final intake manifold model by CATIA V5R18. The geometry was parametrically designed so that after each calculus it was possible to modify every dimension, matching the desired results. In the same picture, the intermediate elements, commented later on, is also shown to better have a good idea of the final study.

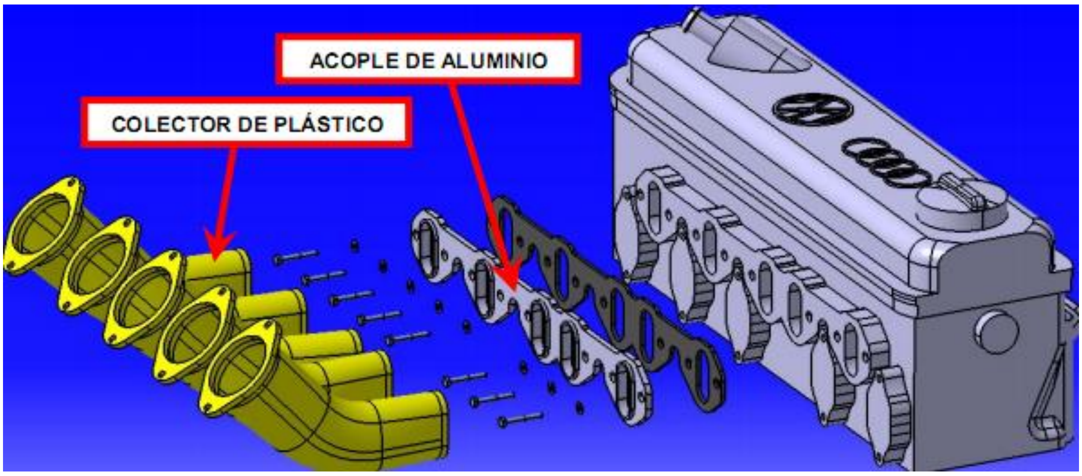


***Figure 2. Final coupling.***

Once the main geometry was designed, it was calculated using the finite elements method. The final model was checked to withstand the generated stresses due to the continuous variable pressure inside. The given study was developed using a final fatigue calculus, showing that the used material was suitable for this implementation. To achieve this goal, the runners thickness was modified several times so that generated stresses were lower than material tensile yield stress.

In the same way, to join the runners to the cylinders head, some options were considered, such as in straight way by means of several screws or using an intermediate coupling system. Finally this second option was developed more in depth as this intermediate component can dissipate all the heat generated in the engine and not transferring it to the plastic runners. Aluminum was finally decided to be used due to its great thermal properties and the low weight in comparison with some other materials like steel among others.

A new problem appeared when it was needed to calculate the way of joining this intermediate coupling to the runners. Two new possibilities were studied as follows:

- Interference coupling using an intermediate element slightly bigger than the runner housing in order to totally adequate both geometries and ensuring the correct behavior for the intake system.
- Adhesive contact between both parts to obtain the same behavior as in the previous case but considering the generated stresses due to the assembly.

Some images of the given calculations are shown in figure 3.

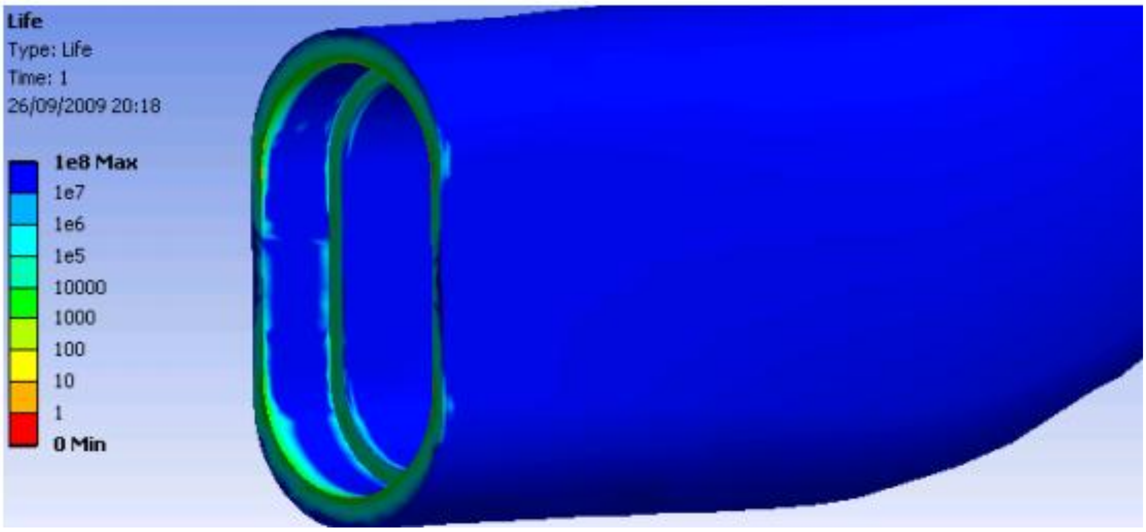


***Figure 3. Fatigue results for 0,05 mm interference.***

All also considered a transient thermal analysis with an initial temperature of 60ºC in the contact with the cylinders head.

Mechanical properties of the selected material are shown in table 1. They were calculated using MATHCAD, as shown in figure 4.

| | |
|---|---|
| Longitudinal Elastic Modulus | $E_x$ = 6549,5 MPa |
| Transverse Elastic Modulus | $E_y$ = 5809,8 MPa |
| Shear Modulus | $G_{xy}$ =2243 MPa |
| Poisson ratio 0º | $\nu_{xy}$ = 0,087 |
| Poisson ratio 90º | $\nu_{yx}$ = 0,0772 |

***Table 1. Analyzed material properties.***

$$E1a(n) := Ef \cdot f(n) + Em \cdot (1 - f(n)) \qquad E1b(n) := Ef2 \cdot f(n) + Em \cdot (1 - f(n))$$

$$E1(n) := \begin{cases} E1a(n) & \text{if } n \le N \\ E1b(n) & \text{otherwise} \end{cases}$$

$$E1(8) = 3.55 \times 10^3 \quad E1(9) = 3.55 \times 10^3$$

$$\beta 1 := \frac{\frac{Ef}{Em} - 1}{\frac{Ef}{Em} + 2} \qquad \beta 2 := \frac{\frac{Ef2}{Em} - 1}{\frac{Ef2}{Em} + 2}$$

$$\beta(n) := \begin{cases} \beta 1 & \text{if } n \le N \\ \beta 2 & \text{otherwise} \end{cases}$$

$$\beta(1) = -0.0459$$
$$\beta(2) = -0.0459$$
$$\beta(8) = -0.0459$$
$$\beta(9) = -0.0459$$
$$\beta(10) = -0.0459$$

$$E2(n) := Em \cdot \frac{1 + 2 \cdot \beta(n) \cdot f(n)}{1 - \beta(n) \cdot f(n)}$$

***Figure 4. MATHCAD use.***

Mechanical properties of the selected material were manually introduced in ANSYS WORKBENCH..

## 3. RESULTS AND DISCUSSION.

It is possible to compare the results obtained in the simulation series by FEM software. Table 2 shows the main results found after the analysis.

| INTERFERENCE (mm) | STRESS (MPa) | DEFORMATION (mm) | FATIGUE (hours) |
|---|---|---|---|
| 0,2 | 674,79 | 0,23 | - |
| 0,15 | 526,92 | 0,18 | - |
| 0,1 | 355,93 | 0,12 | - |
| 0,05 | 224,71 | 0,065 | 1000 - 10000 |

| ADHESION | STRESS (MPa) | CONTACT STRESS (MPa) | DEFORMATION (mm) | FATIGUE (hours) |
|---|---|---|---|---|
| PLEXUS MA-422 | 30,27 | 8,11 | 0,016 | $10^8$ |

***Table 2. Results summary.***

The interference generated was too high to consider this coupling possibility into this study. Even in the best case, with 224,71 MPa, the interference was only of 0,05 mm which not ensured a right contact between both aluminium and composite.

So, as shown in table 2, the right solution was to join both parts with an adhesive. In this case, the contact stress is minimum and the fatigue calculation is suitable for the implementation.

On the other hand, using a laminated part under the interference influence, could create some delaminations on it. This possibility was not considered. Thus, adhesion coupling was again the desired solution for the problem.

## 4. CONCLUSIONS.

It is necessary to keep in mind some important details that were considered both, previously to study the different possibilities or during the design development:

1. The car used in this study was an isolated vehicle and the total cost was the main objective. Complex manufacturing processes used nowadays are very expensive and not suitable for this purpose.
2. In second place, the car used was very old and it was not going to be manufactured anymore. So, in order to improve the engine volumetric efficiency, it was needed to design new components for it. Manufacturing was the simplest way to get small, cheap and easy processing times.

3. Final design was influenced not only by the engine characteristics and the available space into the engine housing, but also by the calculus developed during the whole study.
4. Coupling case was one of the most important studied aspects. Some other issues were studied such as temperatures, stresses, deformations, delaminations or general behavior among others.
5. The final intake system needed more elements, i.e. throttle valve, independent air filters of electronic control unit… but the main purpose for this study were the materials and the 3D model definition.

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