1. Introduction

When the exhaust gas does not get out of car, the car is out of order. This problem is often due to the muffler trouble. The main role of the muffler is to reduce noise. As the exhaust gas passes through various filters in the muffler, the noise is reduced\[1-4\]. Therefore, mufflers are sometimes called by main silences but a significant drop in the muffler's performance to increase power results in a roaring sound in the racing car\[5-7\]. The water drips from the muffler end of a driving vehicle. This is the normal water from the combustion of a mixture of air and fuel but this type of water contains the strong acidity which causes the muffler to corrode. As being noisy when it is shaken by holding the muffler, the corrosion can happen as well as the holes in its appearance. Recently, the tuning mufflers made of aluminum or titanium are also used. By using these mufflers, the exhaust gas maintains the good flow at high speed rotating area in the engine. Basically, the muffler is a good one, effectively reducing noise and allowing exhaust gas to get out\[8,9\]. The mufflers with good conditions for cars and motorcycles have been already commercialized, but this research will have to continue to produce better results. In this paper, the
motorcycle mufflers are designed as three kinds of models. The structural analyses and natural frequency analyses\cite{10,11} are carried out. Through the result of this study, the appropriate configuration can be determined to be the most efficient by applying this result to the design of motorcycle muffler.

2. Study Models and Constraint Conditions

2.1 Study models

In this study, three types of mufflers were designed for each motorcycle by CATIA program. Fig. 1 shows models A, B and C for the analysis. The dimensions of models A, B and C are within 200mm in length and 63mm in diameter. Model A

![Model A](a) Model A

![Model B](b) Model B

![Model C](c) Model C

Fig. 1 Muffler shapes

which is the typical model shape of a motorcycle. Model B has longer outlets in a conventional model and model C has the angles in the shape of the long-drawn outlet. The structural analyses\cite{12-17} were used with ANSYS program.

Table 1 shows the material properties of structural steel and Table 2 shows the numbers of elements and nodes on all models.

| Table 1 Material properties |
|-----------------------------|
| Items                      | Values        |
| Compressive yield strength | 250 MPa       |
| Poisson's ratio             | 0.3           |
| Young's modules             | $2 \times 10^3$ MPa |
| Tensile Ultimate strength  | 460 MPa       |
| Density                     | 7850 kg/m$^3$ |
| Tensile yield strength      | 250 MPa       |

| Table 2 Numbers of elements and nodes at models |
|-----------------------------------------------|
| Model | Nodes  | Elements |
|-------|--------|----------|
| A     | 59244  | 32043    |
| B     | 63229  | 32059    |
| C     | 60198  | 33833    |

2.2 Constraint conditions of models

The fixed part is supposed as the side of muffler at the actual motorcycle. As shown in Fig. 2, the part is in contact with the inlet of the muffler. Since the direction in which vibration and shock are transmitted usually rises from the ground when the motorbike is in operation, the same force on all three models is applied in the lower direction that comes from the ground. The boundary conditions of fixed supports and loads are established as shown by Fig. 2 and Fig. 3.

3. Analysis Result

3.1 Structural analysis
By the structural analysis, Fig. 4 and Fig. 5 show the contours of total deformations and equivalent stresses at each model.

As shown by Fig. 4, the maximum total deformations on models A, B and C show 0.089119mm, 0.40585mm and 0.024503mm respectively. Model C was shown to have the least value as compared with the maximum total deformations of models A, B and C. As shown by Fig. 5, the maximum equivalent stresses on models A, B and C show 101.6 MPa, 139.12 MPa and 46.409 MPa respectively. Model C was shown to have the least value as compared with the maximum equivalent stresses of models A, B and C. The
Fig. 4 Contours of total deformations at each model maximum equivalent stress of model C is higher than model A or model B. But, as the maximum equivalent stresses of models A, B and C are lower than the yield stress of this material, all models are thought to have the sufficient strength at this loading condition.

3.2 Natural frequency analysis

At the muffler models, the natural frequencies on high probability of fracture due to resonance are investigated. The constraint conditions are identical with the fixed supports as shown by Fig. 2. These analyses are carried out with modes 1 to 6 at models A, B and C. Figs. 6, 7 and 8 show the contours of total deformations due to natural frequencies at modes 1 to 6 of models A, B and C.
Fig. 6 Total deformation at natural frequencies of model A
Moonsik Han, Jaegung Cho: 

Fig. 7 Total deformation at natural frequencies of model B

(a) Mode 1

(b) Mode 2

(c) Mode 3

(d) Mode 4

(e) Mode 5

(f) Mode 6
Fig. 8 Total deformation at natural frequencies of model C
respectively. The maximum total deformations of all modes are 108.75mm, 170.04mm, and 106.95mm at models A, B and C. Model A and model C have nearly the same values and these values of the maximum total deformations are lower than model B. Also, the minimum frequencies of all modes are 1126.7 Hz, 422.54 Hz, and 437.02 Hz at models A, B and C. Model A has the highest value as compared with the minimum natural frequencies of models A, B and C. So, it is thought that model A has the highest durability against vibration as compared with the maximum total deformations of models A, B and C.

4. Conclusion

In this paper, the motorcycle mufflers are designed as three kinds of models. The structural analyses and natural frequency analyses are carried out. The following results are derived;

1. At the structural analysis, the maximum equivalent stress of model C is higher than model A or model B. But, as the maximum equivalent stress of models A, B and C are lower than the yield stress of this material, all models are thought to have the sufficient strength at this loading condition.

2. The natural frequencies on high probability of fracture due to resonance are investigated. The maximum total deformations of all modes are 108.75mm, 170.04mm, and 106.95mm at models A, B and C. Model A and model C have nearly the same values and these values of the maximum total deformations are lower than model B.

3. The minimum frequencies of all modes are 1126.7 Hz, 422.54 Hz, and 437.02 Hz at models A, B and C. Model A has the highest value as compared with the minimum natural frequencies of models A, B and C. So, it is thought that model A has the highest durability against vibration as compared with the maximum total deformations of models A, B and C. Through the result of this study, the appropriate configuration can be determined to be the most efficient by applying this result to the design of motorcycle muffler.

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