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# Structural Performance Enhancement of Commercial Vehicle Exhaust Flex Bellows

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**Abstract:** Exhaust system durability performance is one of the most important concerns for emission control. It experiences cyclic loadings; to withstand these loads exhaust systems are equipped with the flex bellow. In this project different exhaust systems are studied. By studying the problem had been identified for particular commercial vehicle exhaust system at the flex bellow component, it is necessary to know the correct dimensions of the flex bellow before the design phase. In this project for the flex bellow component the experimental modal analysis was performed for identifying the vibrational related issues. Simultaneously the vibration isolation data was extracted for the same component. Those two results are correlated, shows that flex bellow component operated at the resonance frequency. To shift the resonance frequencies of the flex, bellow the design parameters are identified as size, length and diameter of the flex bellow. With these parameters the design of experiments is conducted for feasible prototype development. The new designed proto is tested as like previous vibration isolation data and modal analysis, the frequency of the component is shifted from the resonance frequency due to the decrease in the stiffness, the selected parameters are proposed for the new design products.

**Key Words:** NVH, Modal Analysis, Resonance, Stiffness.

## 1. INTRODUCTION

The exhaust systems of the vehicles are the important assembly for the exhaust flow gases and reduction of the noise etc., the exhaust system is affecting by the road loads and load inputs coming from the engine. For avoiding that vibration in the exhaust system it is composed of the flex bellow. But at preliminary design phase of the exhaust system i.e. before selecting the flex bellow component, we need to collect the Road loads data. The main purpose of the flex bellow in the exhaust system is the vibration isolation, for that the component having the efficient stiffness values. Due to the By selection of this component itself we are concentrated mainly on the design parameters of the flex bellow that should have influence on the response (Output parameters) of the component .

Flex Bellow: With the introduction of transverse engines and catalytic converters flexible elements have become an important component in automotive exhaust systems. A flexible connection between the manifold and the rest of the exhaust system is necessary to allow for the rolling movements of the engine. Since for transverse engine orientation the main direction of the exhaust system downstream the manifold is perpendicular to these rolling, considerable axial and bending deflections at the connection must be allowed for. Some torsion also takes place because of the curved path of the exhaust system. Using a rigid joint would give severe vibration of the exhaust system, with noise and quick failure due to exceeded material strength as consequences.

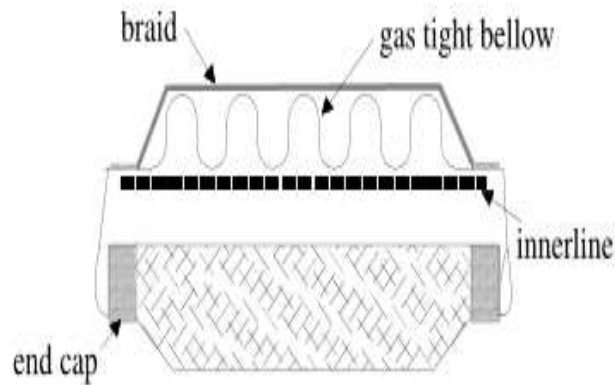


FIGURE 1. General flexible element design

The main aim is to identifying the problems where it had been failing in terms of the NVH causes and finding the remedies to those problems to increasing the durability of the exhaust system of the commercial vehicle exhaust system, Every component in the exhaust system play significant role in terms of durability, wrong selections of the flex bellows it may be failure in the short span of the time, so the customers are faced so many problems for replacing the flex bellow in the exhaust system. As in this project had selected particularly the flex bellow component for solving the existing issues.

#### Design parameters of flex bellow:

- Material
- Length
- Inner & Outer diameter
- No. of ply 's on flex bellow
- Stiffness

## 2. EXPERIMENTAL MODAL ANALYSIS OF SYANDARD FLEX BELLOW

- Vehicle details taken for testing:
- Type of exhaust System: BS3
- No. of Cylinders: 4
- Length of flex bellow: 135mm



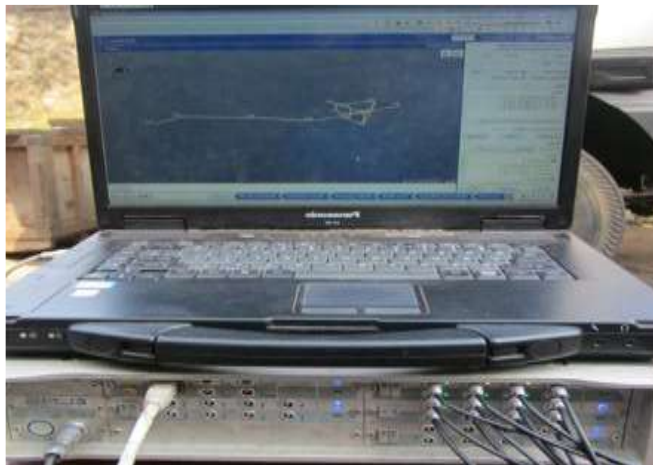
FIGURE 2. Vehicle A second pipe in exhaust system taken for modal testing

For the modal analysis in this project we are taking the entire second pipe for the testing. The modal analysis was done in the vehicle level at the static position. The modal analysis requirements are given below

### Modal Analysis Test Requirements:

- LMS Test.Lab Software
- Data Accusation System
- Tough Book
- Impact Hammer
- Accelerometers
- Cables

From the above list each and every factor is important for the modal analysis, without any one of the above we can 't get the exact results. For the force excitation for some structures shaker testing is used in the replace of the impact testing.



**FIGURE 3.** Test Requirement of modal analysis



**FIGURE 4.** Impact hammer with metal tip

In this project we are excited the structure with the impact hammer, the selection of the impact hammer tip will be depending on the type of the structure to be excited. Here the entire second pipe in the exhaust system is the metal pipe so we are interested to put the metal tip as the Metal tip. The impact hammer with metal tip used in this test is shown below

### Modal analysis Procedure:

- Initially in the testing procedure the list of the accelerometers used and their sensitivity all remaining data are included in the tough book.
- The next step is the required geometry, that is going to analyze the modal is created in the tough book with help of the LMS Test.Lab.

- In the creation of the geometry different types of geometry options in terms of the different coordinate systems are available like Cartesian, polar and cylindrical. According to the requirement we are chosen the cylindrical coordinate system.
- After completion of the geometry of the structure, location of the accelerometers is decided, if we are placed more number of accelerometer we are getting more responses, the output results may be come as accurate.
- The accelerometers are placed on the structure with the adhesive materials; the accelerometer is connected to the Data Acquisition system (DAQ) through the cables.
- The impact hammer also connected to the DAQ via cable.

With the impact hammer the structure is excited, where the force transmitted to the structure is measured. The response of the structure is often measured using an accelerometer. Typically, the force used to excite the structure is measured on the lowest channel of the data acquisition system. Although this is not a requirement on many data acquisition systems today, but some of the test engineers still follow this practice. The response signal(s) is measured on the remaining channel(s) (depending on whether a dual or multichannel system is being used). In order to start the data acquisition measurement, typically the measurement is started from a trigger from the impact device. Some minimal voltage must be specified in order for the data acquisition system to start the measurement process. A trigger level of 10% to 20% of the maximum voltage of the measured force is a good value to use for most tests performed. In many data acquisition systems, a pre trigger delay is specified to capture the entire transient of the impact device.



FIGURE 5. Impact testing of the flex bellow component

#### Vibration Isolation Taken for Vehicle A:

- Test Requirements:
- LMS Test.Lab
- Data Acquisition System
- Tough Book
- Accelerometers

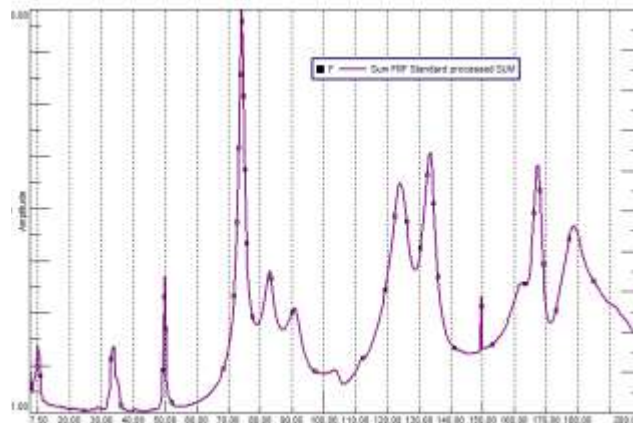


FIGURE 6. Sum FRF of the standard flex bellow

The tri-accelerometer position is placed at the active and passive sides of the flex bellow component. Because our interest is comparison of vibrations how much coming at the active side and the flex bellow component is how much it is isolate the vibrations.

The below fig. shows the clear picture about the accelerometers location of flex bellow

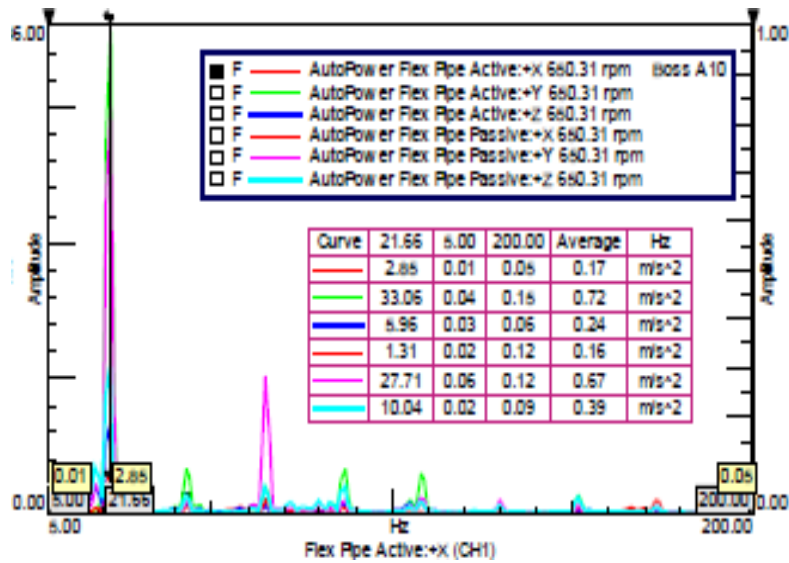
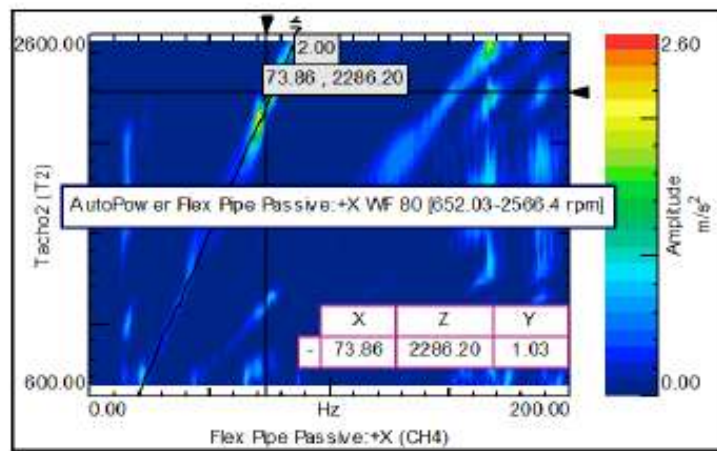


FIGURE 7. Vibration Isolation of standard flex bellow



Resonance on X-axis at 73.86Hz

FIGURE 8. Vibration isolation and resonance checking

### 3. DESIGN & ANALYSIS OF FLEX BELLOW

The flex bellow component is specified by the length and diameter. In this project the component is varied by the length and stress analysis is performed.

**Design:**

- Design parameters for the standard flex bellow:
- Flex length of flex bellow = 135mm
- End caps length =25mm on both ends
- Diameter of flex bellow =100mm
- Diameter of end caps =86mm
- No. of corrugations = 19

- Pitch of corrugations = 6.45mm
- Design parameters for the New flex bellow:
  - Flex length of flex bellow = 185mm
  - End caps length =25mm on both ends
  - Diameter of flex bellow =100mm
  - Diameter of end caps =86mm
  - No. of corrugations = 28
  - Pitch of corrugations = 6.45mm
- Both are modeled in the CATIA software.by varying the length and same diameter. The no.of corrugations are increased in the new flex bellow compared with the standard flex bellow.

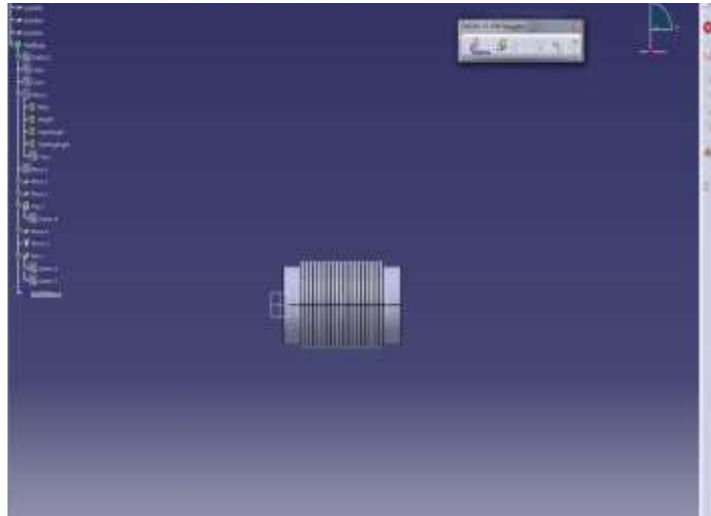


FIGURE 9. CATIA model of standard flex bellow

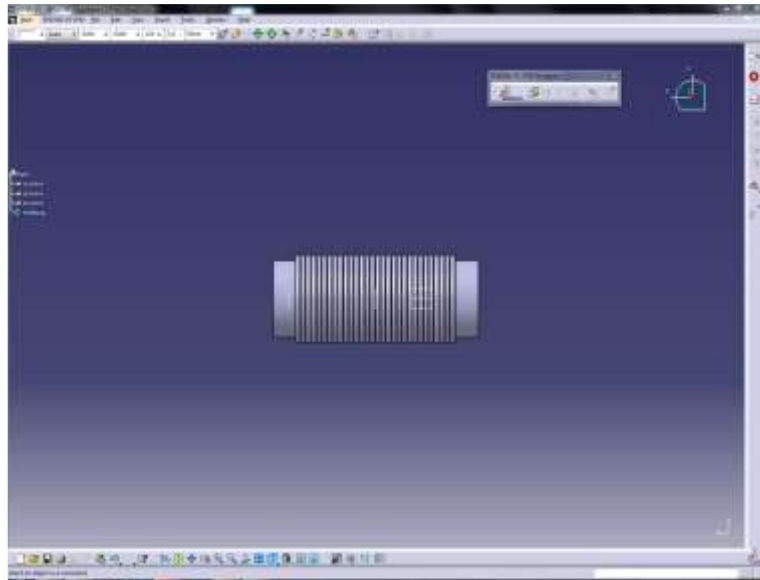


FIGURE 10. CATIA model of the new flex bellow

**Analysis:**

The flex bellow component is affected to the structural and the thermal loads due to the its position of placing in the vehicle level. We are studying about the flex bellow is placed in the exhaust system so it affected by the both the loads due to the engine movements, road loads, and exhaust gas flowing through that component. Present in this thesis considered only the structural loads, because we are analyzing the flex bellow component in terms of the structural vibrations only. The flex bellow components are

modeled in CATIA are imported into the ANSYS WORKBENCH software.

- Total Length of Component: 185mm
- Flex coupling length = 135mm
- Type of Meshing: Tetrahedral
- No.of Nodes: 87146
- No.of Elements: 37254
- Load applied on the Active side of flex bellow = 400N
- Passive side is fixed.

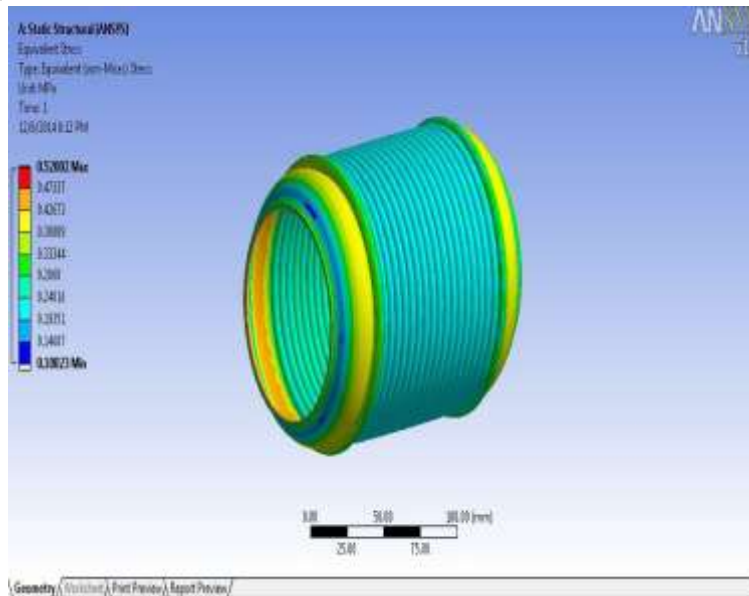
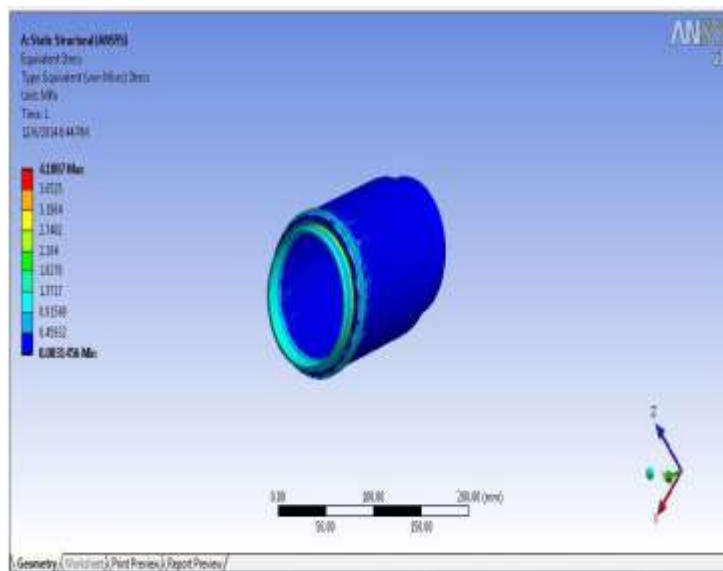


FIGURE 11. Analysis of standard flex bellow

- Total Length of Component: 225mm
- Flex coupling length = 185mm
- Type of Meshing: Tetrahedral
- No.of Nodes: 131756
- No.of Elements: 58288
- Load applied on the Active side of flex bellow = 400N
- Passive side is fixed.



**FIGURE 12.** Analysis of New designed flex bellow

- Material Taken for Design & Analysis: Stainless Steel
- Minimum Stress = 0.0031456 MPa
- Maximum Stress = 4.1087 MPa

Some of the results are captured from the Design & Analysis of the flex bellow component. Those are

- Both flex bellows are modeled in the CATIA software and imported to the ANSYS Software.
- The input load is given to the both components is same i.e. 400N on the active side of the flex bellow, another side both are fixed condition.
- The new flex bellow shows that, it will bear the more loads as compared with the standard flex bellow.

#### **4. EXPERIMENTAL MODAL ANALYSIS OF NEW FLEX BELLOW**

From the results of the stress distribution and the statistical stiffness results, we are going to test the same Vehicle A with the new flex bellow. In this the natural frequencies are extracted and those will be compared with the vibration isolation data for resonance checking.

##### **Vehicle details taken for testing:**

- Type of exhaust System: BS3
- No. of Cylinders: 4
- Length of flex bellow = 185mm

In this also the force excitation given by the impact hammer same metal tip as used for the standard flex bellow.

Same procedure is followed as the previous standard flex bellow and with reference of the previous modal analysis chapter. The new flex bellow with the accelerometer placed is shown below.



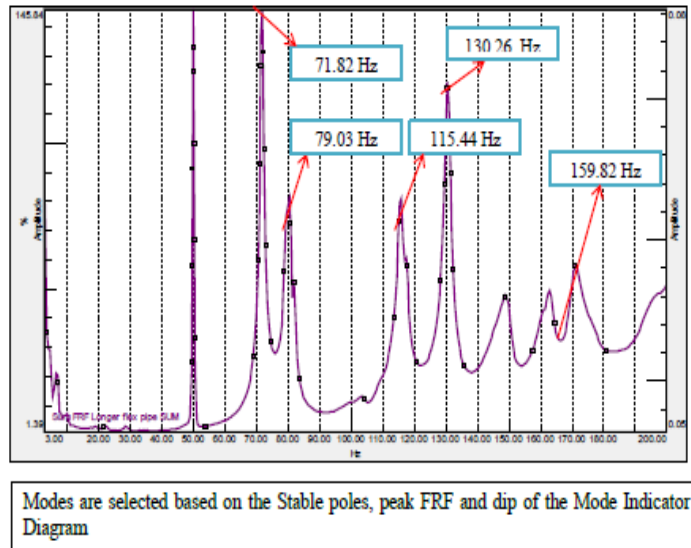
**FIGURE 13.** Vehicle A second pipe with new flex bellow in exhaust system taken for modal testing



**FIGURE 14.** Acceleration positions on the flex bellow component

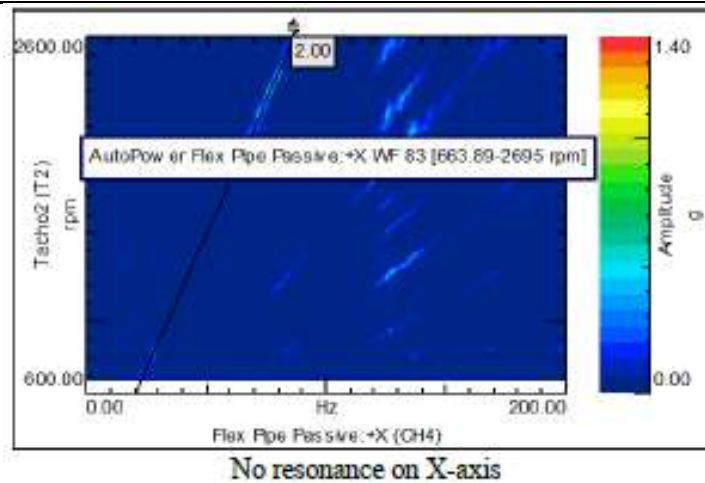
The response is captured from the flex bellow through the accelerometers those are the analogous signals, it is difficult to analyze the analogous signals so the DAQ is converted the analogous signals to the digital signals; at here we are analyzing the response.

The FRF is captured from the flex bellow in the preprocessing stage those will be analyzed in the post processing stage, i.e. the all FRF are summed because of easy identification of the modes at the peaks and it is difficult to analyze each single FRF so for simplicity of the analyze the FRF is clubbed as the sum FRF and analyzed. The X-axis is the frequency in this we are interested to take 3-200Hz. In the Y-axis is the amplitude of the response that is captured. The sum FRF will shows the data i.e. the amplitude of response is captured in the frequency range of the 3-200Hz.



**FIGURE 15.** Frequency of the new designed flex bellow

After taking the natural frequencies from the new flex bellow these are compared with the excitation frequency.



**FIGURE 16.** Resonance checking on X-Axis

It is clear that from the above results the new flex bellow didn't show the resonance on the any of the 3 axis, the standard flex bellow showing the resonance in the all the axis , with replacing of the new flex bellow we are avoiding the resonance frequency of the flex bellow

## 5. RESULTS & CONCLUSIONS

In this project mainly conducted the experimental modal analysis and vibration isolation data, the materila was optimized for the avoiding the resonance condition. Here two initially flex bellow was shows the operated at the resonance frequency of 72.3HZ, to overcome the problem the materila was optimized. After detailed studying the compoennt structure the stiffness is reduced through the materila optimization for avoiding the resonance the same comoponent after stiffness reduction operated at the 78 hz which is shifted from the resonance frequency. With this the increase in life of the compoennt was achieved.

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