Engineering Failure Analysis 60 (2016) 250–260

Contents lists available at ScienceDirect

Engineering Failure Analysis

journal homepage: www.elsevier.com/locate/engfailanal

Nobel approach in signifying damage for a bellows type flexible joint

Tae-Kyung Jang [a], Byeong-Soo Lim [b], Moon-Ki Kim [a,*]

[a] School of Mechanical Engineering, SungKyunKwan University, Korea
[b] School of Multi-disciplinary Engineering, Addis Ababa Institute of Technology, Ethiopia

ARTICLE INFO

Article history:
Received 28 January 2015
Accepted 18 November 2015
Available online 22 November 2015

Keywords:
Damage analysis
Fatigue properties
Bellows type flexible joint

ABSTRACT

The durability of an exhaust system, particularly for a flexible joint, has been addressed in terms of damage augmented by energy spectral densities. Movement of a flexible joint in motion is calculated by solving forward kinematics of the Stewart platform, converting displacement signals obtained by a set of potentiometers into a Cartesian pose. Those time series are then projected onto the uni-directional field thus defined separately, i.e., damage for the application of the Minor rule and energy for power spectrum densities. Parseval's theorem allows us to bridge two fields so that one can access not only information on fatigue properties, but also on effect of aging in the presence of shock and impact.

1. Introduction

During last decade, the most noticeable structural changes in the design of exhaust system for a passenger vehicle would be the use of Medusa-like exhaust manifolds, the application of which can be traced in Formular 1 machines. They straighten and shorten the routing of exhaust-gas flow, thereby reducing back pressure drastically. They give a significant power boost without sacrificing fuel economy. Moreover, engine downsizing, an attempt to provide lighter yet powerful vehicles, often produces hotter exhaust gas in association with fully-fledged injection technologies. A decade ago, the exhaust-gas temperature of a mid-size gasoline engine was no more than 500~600°C. Now, it could exceed 1000°C easily. Materials such as higher grade stainless steels must be chosen to endure hotter exhaust gas. Tougher emission regulations require to add a combination of catalysts closer to engine. The exhaust system becomes heavier, hotter and more expensive.

To secure durability of the exhaust system, a more effective method to decouple it from any driving circumstance has been sought. Fig. 1 shows the typical hanging system of an exhaust pipe. The engine rolls and heaves simultaneously on top of engine mounting rubbers, while the exhaust system is hanged on hard points welded on the chassis. It allows us to keep the movement of the exhaust system within the limited configuration space. In other words, it has to be protected either from engine locks or from bad-road excitations. To achieve these goals, engineers have been using a bellows-type flexible joint in front of the exhaust system (Fig. 2). It should be, however, recognized that such a layout works at the expense of the shortened life cycle of a flexible joint.

Proving durability of the exhaust system through bad-road tests has become a gate check that has to be successfully completed before signing off the serial development. A series of bad-road tests has been developed to pinpoint the structurally weakest design in the system. We can classify the type of bad-road tests into two groups as listed below,

* Corresponding author at: Department of Mechanical Engineering, SungKyunKwan University, Korea.
E-mail address: mkkim@me.skku.edu (M.-K. Kim).

http://dx.doi.org/10.1016/j.engfailanal.2015.11.051
1350-6307/

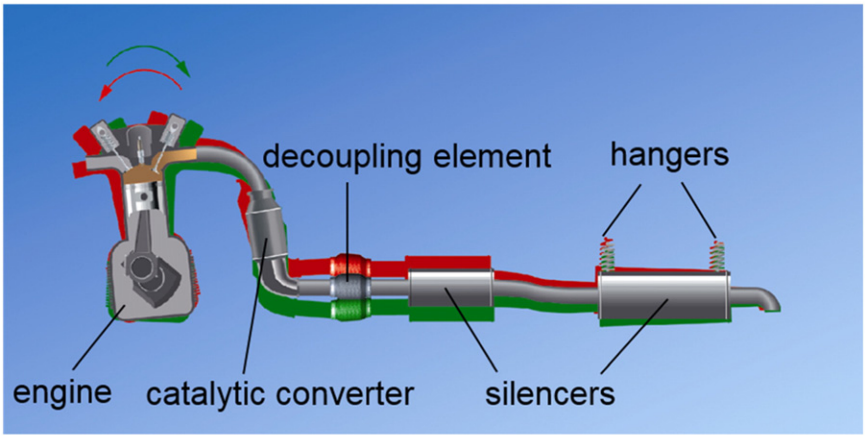

Fig. 1. Hanging system: a typical configuration of the reversed exhaust manifold [1].

- Constant speed tests: driving speed of a test vehicle is fixed on the predetermined constant value, so that no inertia forces are provoked while driving. Belgian blocks and cross country driving (X/C in short) are the two representatives. They are designed to measure robustness of the exhaust system from excitations passed through the chassis.
- Varying speed tests: varying amplitude of acceleration or deceleration of a driving vehicle is specified in details, so that the exhaust system at hand undergoes rapid changes of inertia forces via a sequence of shocks and impacts. Anti-lock braking system (ABS) maneuver and idiot start-and-stop are quintessential in this respect. They are designed to probe the life cycle of the exhaust system under extreme maneuvers.

There has been a great amount of research to assess the life cycles of automotive parts and components via the stress based fatigue analysis [2]. For example, Cartesian poses were calculated from relative motion around the flexible joint through a set of potentiometers, while driving on the formalized bad-roads, such as Belgian-blocks and X/C drivings. They are signified in a unidirectional displacement field to determine the life cycles of the flexible joint in terms of damage. It has been tested and proven to be useful among relevant engineering societies. With the advent of a data crunching technique, such a quantitative measure becomes standard in the vehicle validation processes.

However, there have been cases in which one cannot anticipate a certain degree of reliability with the traditional peak counting damage calculation. Even with the damage level within the admissible range, it is not difficult to find cases of early fractures and failures. It is especially true for the flexible joint interfacing the engine and exhaust system (Fig. 2). We are trying to see 'the specific cases' deep inside to answer the question "what's behind there?"

2. Objective

In general, the exhaust system moves along with the direction of a driving maneuver. When accelerating or decelerating a car, the movement of the exhaust system, however, deviates from that of the moving vehicle body due to the changes of inertia forces and moments. Engineers often forgot that the exhaust system could possibly undergo relative motion at the outset of the given layout. Being presented in the form of shocks and impacts, reaction triggered by ABS engagement could damage the exhaust system furiously, resulting in stress migration looking for the weakest in the structure. In such, it would be very difficult to assess the life cycles of the flexible joint by using the strength-based fatigue analysis, i.e., a peak counting technique. It takes into account how many peaks are coming, but not how quickly they occur.

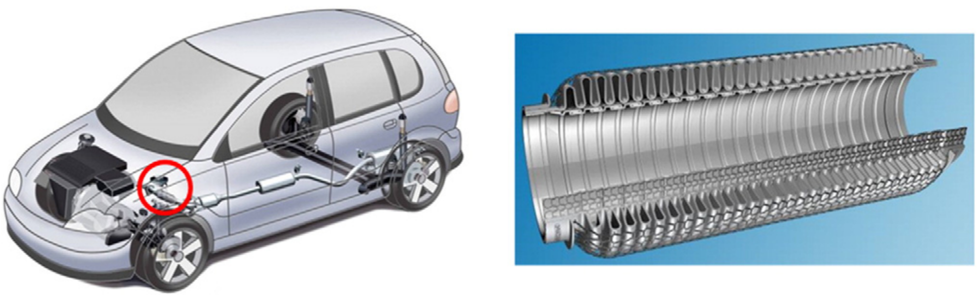

Fig. 2. Flexible interface of the exhaust system and its bellows type flexible joint.