THE USE OF FATIGUE TO DESIGN STRUCTURES UNDER VARIABLE LOADING

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The paper discuss some main topics with relation to the use of fatigue as a parameter to design automotive structures under variable loading. The covered topics are theory of random process and random variables. The concept of stochastic process that helps to characterize the random loading is presented. Nature loads used in analytical and experimental design processes are covered too. In analytical design process, finite element analysis simulating the services loads helps a lot before create the prototype to be submitted to an experimental test; in experimental design process, the role of the test laboratory is to provide data to be used in the analysis procedures, the relation among them to the life prediction is discussed. The fatigue criteria used in automotive structures is discussed. An example of the design process is shown with a specific component (battery tray).

INTRODUCTION

The engineering procedures used in the automotive industries to promote structural integrity in cars and trucks is continuously evolving. Significant changes are still taking place in instrumentation, analysis procedures and methods of handling and analyzing data. As long as these techniques continue to evolve, engineers will have the opportunity to utilize these new resources to make improvements in their fatigue design procedures.

To plan a product, the engineering department may need to have a survey completed to determine the needs of the customer. In each area is possible to determine the range of expected usages. The usage pattern of many products primarily results from the different applications the product as it is being used by the customer. The manner in which a product interacts with the environment during its use produces forces on it and it is necessary to characterize their magnitude, frequency, rate of change, etc.

To evaluate the durability of a product for any specific configuration, usage area and type customer, the designer must obtain and evaluate load information in analytical and experimental techniques.

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The heart of the design process is the set of analysis tools that the designer employs. The use of finite elements analysis is shown at figure 1 and/or scale model testing using simulated service loads should normally be considered in the early stages of the design process.

Many of the design deficiencies can thus be eliminated by using either one or both of these techniques before the first prototype is built; in most cases the test laboratory is called on to provide data to be used in the analysis procedures at SAE (1).

THEORY OF RANDOM PROCESS

The theory of random process has evolved as a generalization of the concept of random variables. The random variable can be used to model random events for which the outcomes of repeated trials are a real or complex number. In many problems the outcome of a trial is not a number but a function of one or more parameters, such as time or space or both. In such cases, the outcomes of each trial is called a realization or a sample function and the collection of all possible sample functions is called the ensemble of the random process. For a fixed value of the parameters, a random process is a random variable, and therefore it may be looked upon as a parametered family of random variables.

Figure 2a shows the realizations of a random process $X(t)$, where t is the parameter- say time. The superscript $j = 1,2,\ldots$ in $x^j(t)$ represents the jth realization of the random process $X(t)$. Nigan (2) fixed times $t = t_1$ and t_2, $X(t_1)$ and $X(t_2)$ are random variables and $x^j(t_1)$ and $x^j(t_2)$ their jth realizations . Most often, the parameter (or dependent variable) in the random functions is time, and the concepts of stochastic process are commonly used. A stochastic process is a family of random variables, its specification is similar to that for random vectors; the differences are associated with the fact that the number of random variables may now be (countable or uncountable) infinite. It turns out, however, that an infinite number of random variables can be described by means of finite dimensional distributions.

For an arbitrary finite set of t-values, say $\{ t_1, t_2 \ldots t_n \}$, the random variables $X(t_1), X(t_2), \ldots, X(t_n)$ have a joint n-dimensional distribution with the distribution function,

$$F_{t1,t2,\ldots\ldots,tn}(x_1, x_2, \ldots\ldots, x_n)$$

$$= P\{ X(t_1) < x_2, X(t_2) < x_2, \ldots\ldots\ldots, X(t_n) < x_n \} \quad (1)$$

The function $F_{t_1, t_2, \ldots\ldots, t_n}(x_1, x_2, \ldots\ldots x_n)$ is called the n-distribution function of the random process $X(t)$, figure 2b shows an example of a stochastic processes, with more details in reference (3).

Like random variables, stochastic processes can be conveniently described by their moments; the simplest characteristic is the mean or average value, $m_X(t)$. It is defined as a function that, for each t, is equal to the mean value of the corresponding random variable, i.e.

$$m_x(t) = \langle X(t) \rangle \qquad (2)$$

NATURE OF LOADS

In service, vehicle components are in most cases subjected to variable loads. The structures represent more or less complicated elastic systems, time-varying operational loads can excite their natural modes. Therefore, the response, which is in the form of a stress-time history at a point of the structure, that is far enough from the point of load introduction , may show differences with regard to amplitudes as well as to frequencies compared with the corresponding load-time history.

To determine the design load spectra, different procedures can be used. But for all of them, services measurements are needed - either to determine the data for different operational loading conditions or even also the customer usage as covered by Grubusic (4).

Below are some examples of the strategy to obtain the spectrum:

1- the measurements are carried out with a vehicle prepared with sensors by a test driver over preliminary chosen road segments,
2- the measurements are carried out with a vehicle prepared with sensors used by different drivers over road segments
3- the measurements are carried out with a vehicle prepared with sensors use by different drivers on different road segments,
4- the measurements are carried out with a vehicle prepared with sensors use by a test driver who is following customers during their usage.

To determine the spectrum of loading to fatigue evaluation of the vehicle components and assemblies is necessary to follow some conditions that are :

a) The test must take into account all possible loading conditions, including values during customer usage which would be seldom achieved. This subject is of decisive importance for the vehicle components safety, due to product liability requirements.

b) The tests should be accelerated only by adjustment of the load spectrum in the medium and high load levels and omission of non-damaging high-cycle, low intensity loads, predominantly originating from operational conditions during straight driving over smooth roads.

EXPERIMENTAL PROCEDURE

The engineering design and analysis process flow chart shown in figure 1 gives the design activities and information flow used in product design. With current computer facilities these areas are linked with network and compatible softwares and the data can be shared among those areas :

a) data acquisition and classification tools determine load data for a fatigue test or for analysis of the structure;
b) data editing and modification tools accelerate a test and improve results by removing insignificant, non-fatigue contributing data.;
c) laboratory testing tools simulate or evaluate a product's response to a load environment;
d) test data monitoring tools determine how the specimen reacts to the load environment over a period time;
e) laboratory data analysis tools analysis the results of field or laboratory testing to determine a product's life.

This paper shows the process of design of a car battery which is instrumented with accelerometers and strain-gages in hard points. The results of the measurements of the battery tray baseline gives input to the CAE model, and the guidelines to the designer. The acquisition of data is on several roads tests conditions like cobblestones, shuck holes, and city road. The results are shown is table 1. The validation of proposal will be done in a proving ground with accelerated durability test over 12,000 Km.

DESCRIPTION OF FINITE ELEMENT MODEL

The model was done using Ideas version 1.3c from SDRC (5); the model contain battery support and tray, being the tray the principal target to development. The assembly has 6,800 thin shell elements being 3,300 of tray battery and 3,500 of battery support shown on figure 3a and 3b respectively.

The restraint of the model is made by considering that the union of the battery tray and the battery support is done by rigid elements and the tray support with the front end is done by rigid elements simulating the welds points. The restraining joints of union battery tray and engine mount is simulated restraining all displacements and rotations. The major accelerations that are used in the model are : 20.0 m/s^2 (-x); 20.0 m/s^2 (y) and 40.0 m/s^2 (-z).

The intention here is to find a good agreement between thickness and durability of the battery tray and support; to do that some proposals are evaluated and the results are shown on table 2.

TABLE 1 - Experimental Results

Measurements by track (MPa)		**Measured frequencies (Hz)**	
wheel fight	22.9	wheel fight	10.0
chuck holes	25.8	chuck holes	12.0
cobblestones	17.5	cobblestones	24.0
cattle crossing	22.9	cattle crossing	15.0
FEM	31.3		

TABLE 2 - Analytical Results

Model	**Stress (MPa)**	**Frequency (Hz)**
current	200 .0	35.54
proposal 1	180.0	26.11
proposal 2	130.0	27.84

THE FATIGUE CRITERIA

Fatigue life criteria prediction techniques play an ever-expanding role in the design components in the ground vehicle industry. Many companies employ such predictive techniques for applications ranging from initial sizing through prototype development and product verification. Ricardo (6) and Kelkar (7) gives some examples of the application. In the present case the criterion of fatigue stress is 160.0 MPa and the component will be instrumented to validate the FEM proposal. The component will be evaluated in a proving ground test and it should not cracks after durability tests; this represent a normal service life of 160,000 km.

CONCLUSION

The paper shows some aspects of the development of an automotive structure, the development of which is in progress, the analytical work is done, and in next step the component will assembled in a vehicle to support a durability test of 12,000 km.

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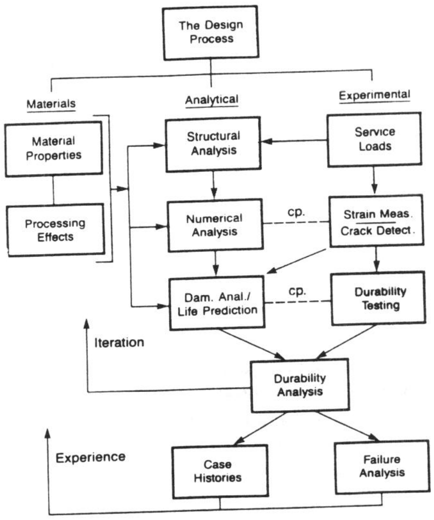

Figure 1 Design Process

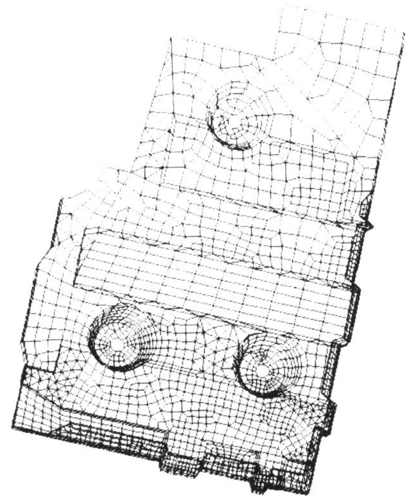

Figure 3a Battery Tray

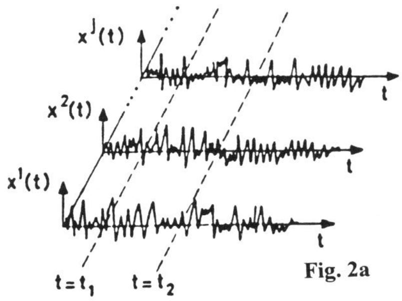

Fig. 2a

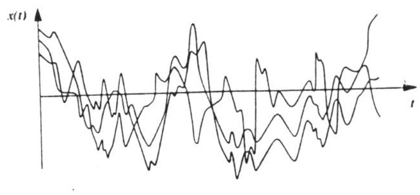

Fig. 2b

Figure 2a Ensemble of a Random Process
Figure 2b Stochastic Process

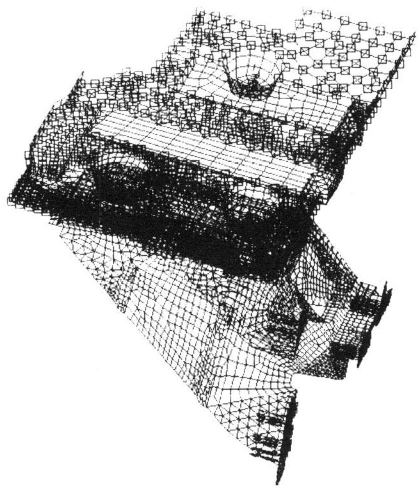

Figure 3b FEM Assembly Model