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# A LABORATORY TOOL FOR THE STUDY OF VEHICLE VIBRATION PERFORMANCE

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#### ABSTRACT

The study of the vibration characteristics in machines has taken a front iseat in engineering effort. This is particularly true in the automotive industry, where marketing a vibrating vehicle is unacceptable. Today's automobiles are a complex spring-mass-damper system which is excited into various modes of vibration. The vibrational modes falling in 10-200 Hz are termed "structure shake", and produce distrubances seen and felt by the vehicle occupant. The knowledge of an objectionable vibration in development programs. Therefore, the aim of this work is to introduce a method by which the vehicle vibration performance can be investigated in the laboratory. A chassis dynamometer was used to simulate the road-going conditions. The measurement and analysis techniques are presented herein. Samples from the results obtained for van and small saloon vehicles are included to illust-irate the suitability of the measuring technique and the instrumentation system used.

### INTRODUCTION

As the vehicle is traversed over varying road surfaces and operated through a varying speed range, it is excited both externally and internally into various modes of vibration. One of the main objectives of automotive engineers over the years has been to design and develop vehicles in which the :passenger's perceptance of these vibrations, either through, sight, feel, or hearing is held to an absolute minimum under all driving conditions. Une of the earliest techniques for accomplishing this, and one which still to some degree in use today, is the subjective, seat-of-the-pants evaluation by experienced personnel. Intuitive changes would be made in the vehicle and each one evaluted until satisfactory arrangement was arrived at [1]. This method of solving structure problems leaves a lot to be desired as far as defining the problem and arriving at an efficient, economical solution in a minimum amount of time. The static bending test came into universal use. The technique considers the vehicle structure as a beam. The beam was supported on knife edges at the front and rear wheel centrelines, and either a constant bending moment was applied to each end or a torque was applied one end to produce beaming and torsional deflections. Vertical deflection

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at various points on the structure was measured and plotted to give static bending curves [2,3] . The results gave valid comparisons between cars and some indication of their structural characteristics. Usually, a good deal : of experience with the baseline model was required in order to predict the performance of the new model from the static bending curves. These results told very little about the vibration characteristics of the vehicle. The electrodynamic shaker came into use as another tool in studying structure vibration characteristics. It is in widespread use today and allows the engineers to make valid studies and analyses of the dynamics of an autom-: otive structure. Through the use of multiple shaker systems, it is possible to excite in the laboratory the various modes of vibration of an automobile and study their tuning characteristics and the coupling between them. The : inputs from the shakers can be fed directly in the structure at one or many points [4], or can be fed into the wheel spindles to more closely approximate road inputs [5,6] . Usually, the electrodynamic shaker study is : concerned with exciting and separating pure modes so that various vibration analysis techniques can be applied to the system under study.

As the knowledge of vehicle structure dynamics expanded during the past few years, it becomes more obvious that, in addition to pure inputs to the structure, a complete analysis must include inputs that simulate road inputs as closely as possible. Since road inputs consist basically of a vertical force or displacement acting at the contact patch of each tyre, this then becomes the logical place to introduce laboratory inputs. By doing this, it is then possible to duplicate in the laboratory the actual vibrations(or shake) experienced on the road, bringing all vehicle parts into play, and allowing complete instrumented and subjective analyses of is the vehicle structure under controlled conditions, this is can be done by road simulator. However, the present paper does so by using a chassis dynamometer. The measuring system used is described and some typical is results presented.

## THE NEED FOR TESTING

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The explanation of vibration generally begins with the theoretical development of formulas describing the vibration of arbitrarily chosen simple systems, such as the spring-mass system with one degree-of-freedom as shown in Fig. 1.a. Equations are developed that describe the vibration characteristics of the system and then damping is usually added and the equations modified accordingly.

If another spring and mass is added as shown in Fig. 1.b, the system contains two degrees-of-freedom, and the equations describing its vibrations become more complex. As more springs, masses, viscous and coulomb damping : are added, the number of degrees-of -freedom increases as does the complexity of its characteristic equations. Although some of the automobile's mechanisms may be represented by a mathematical model involving an awesome: array of formulas, the only practical way is to measure the actual and total vehicle response is through well planned testing. Various testing approaches used may be generally divided into three categories; namely, evaluation, : diagnostic and development. The evaluation test is the basic form of a vibration appraisal. It may include making individual or jury subjective ratings or quatitative measurement, or both, and frequently involves simple comparisons. However, the analysis in this work concerns with an laboratory evaluation test .

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Fig. 1 Simple spring-mass system

# SIMULATION AND NEASURING SYSTEMS

The simulation procedure for the road conditions can be made by using a chassis dynamometer and is shown schematically in Fig. 2. This type of



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dynamometer is in Mechanical Engineering Department, El-minia University. It gives the possibilty to simulate to a very large extent all actual road conditions, so that the adjustment and checking for the whole vehicle can : be done. It consists of two rollers of 2000 mm. diameter and the circumference is exactly 1000 mm., which support the rear vehicle wheels during test. The rollers are most carefully balanced, both dynamically and statically. : They designed for quiet operation and have close fitting protective covers to allow maximum safe access to all parts of the vehicle underside. In addition to absorbing or producing power at the vehicle rear wheels, the eddy-current brake has the added capability of simulating varies road surface. Simulations of vehicle inertia, frontal wind(air) resistance, and grade loads are possible through electronics incorporated into the operator's console. The brake is dimensioned to measure 150 KW and 5000 N. The allowable maximum speed is 180 KM/hr. In order to prevent over-speeding the brake automatically increases the load at approximate this speed so that the speed cannot exceed 190 KM/hr. The brake is water-cooled, and the water supply is controlled automatically with a built-in thermostatic sensing element. A high capacity blower unit is equipped for radiator cooling, engine, under-: body spot cooling, and a special localizer water system for tyre roller contact cooling. The control of the dynamometer is from a complete operator's console, or from a remote control suitable for use outside or inside the : vehicle. A unique feature of the vehicle dynamometer is its capability to switch the test vehicle from one test surface to another during operation. The test vehicle may be operated over either of these surfaces and may be : switched from one surface to the other.

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The measuring system is also shown in Fig. 2. The system is partially digital in operation. A uni-gain piezoelectric accelerometer is used. It generates an electrical output when subjected to mechanical shock or vibration. Over a wide dynamic range and frequency range its electrical output is directly proportional to the acceleration of the vibration applied at its base. The uni-gain type indicates that their charge sensitivity has been specially adjusted to within 2% of a convenient value. The electrical signal output from the accelerometer is intered to a charge amplifier. The amplifier is a comprehensively equipped and intended for general vibration measurements with a piezoelectrical accelerometer input and for underwater sound measurements in conjunction with piezoelectric hydrophones. It can be powered from internal batteries or an external DC power supply and is equally suitable for portable use in the field and for general laboratory use. The amplifier output is routed to the high resolution signal analyser. which represents a significant innovation in the world of real time FFT analysis. The analyser has the capability of analysing the transient and non-stationary signals. Further a unique zoom feature which preserves the time function allows a 4000-line spectrum to be generated from a single time record. It consists of a combined transient recorder and fourier analyser. The transient recorder has a 10 K sample memory, and is equipped with an extremely flexible trigger allowing the analyser to analyze both : continuous and transient signals. A graph plots for the analyser output both in frequency and amplitude can be taken through a X-Y recorder. It is outstanding dynamic performance and versatility, combined with its simple : and straight-forward operation. Its writing system can accept up to A4 paper size. The pen and the pen carriage are driven by low inertia servo motors which are fully protected against excessive drive current and overloads. For more description with other application by using such measuring system can be found in [7]

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# APPLICATIONS

Vehicle Preparation and Test Procedure

Two applications were made in this study. The first one was applied on Van vehicle which used for engine vibration tests, and the second one was applied on small Saloon vehicle which used for road surface vibration tests. Some specifications for these vehicles are listed in Table 1.

No.	parameter	Van	small Saloon
1 2 3 4 5 6 7	tyre size wheel base,m wheel track,m height,m engine max. power,HP gear-shift No. gross vehicle weight (GVW),Kg	180-13 2.75 1.47 1.45 95 4 & rev. 1200	200-13 3.69 1.69 2.22 91 4 & rev. 1 <i>5</i> 00

Table 1 Some vehicles specifications

Fig. 2 shows the van vehicle setting on the dynamometer along with the measuring instrumentations. Prior to testing, the tyres inflation pressure was measured and adjusted on 2.55 atm for each vehicle. It is recommended to increase the inflation pressure up to 50% for long run test. This will decrease tyre rolling resistance and consequently increase tractive force little. The cooling water and oil lubrication were checked, the hub caps and loose wheel weights were removed. The blower unit was switched on when the cooling water in the radiator has reached the normal working temperature of : each vehicle. The vehicle has been driven at moderate speed until the engine has reached the normal working temperature. The tractive force preselector has been set to a value corresponding to the type of road surface condition. By this way, a constant and indefinitely reproducable load in the full speed range of the dynamometer irrespective of the durion of the test can be obtained. Consequently, the vehicle can be driven at any gear-shift and at any speed. It is well-known that the vibration generated from either road surface or engine is transmitted through their connection points with the body. Fig. 3 shows the layout of rear engine mount of Van vehicle considered. for engine vibration.



Fig. 3 The layout of rear engine mount of Van vehicle



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Once all the initial provisions of measuring system such as adjustment, calibration and installation of vibration accelerometer, charge amplifier, analyser and X-Y recorder have been made, a details measurements are begun
by setting the vehicle speed as required and according to the chosen gearshift. The tractive force may be setting equal to zero or to any value corresponding to the type of road surface. The analyser can produce either instanteneous or average spectrum. Bearing in mind that the frequency range taken for engine vibration is 5 KHz while in road surface vibration is 0.2 KHz. Table 2 lists the types of road surface used with their coefficients of rolling resistance.

Comparison and the second second second		ling resistance	
No.	type of road surface	Coeff. of roll. resistance f, mean value	
1 2 3	Cobblestone pavement Gravel road Asphalt-concrete	0.023 - 0.030 0.020 - 0.025 0.018 - 0.020	A Contraction of the second se

Table 2 The types of road surface and their coefficients of rolling resistance

Engine Vibration Results

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Having applied the above procedure on the Van vehicle in order to measure its engine vibration. Samples of the results obtained are shown in Figs. 4, 5,6 and 7. The frequency range used is 5 KHz and the vibration response is presented as vibration acceleration referance to  $1 \times 10^{-4}$  m/sec<sup>2</sup>. The measuring points are being near-side and off-side of the rear engine mount.





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Fig. 7 Vibration response at near-side point for engine vibration

Figs. 4 and 5 show the vibration responses measured at near-side point when the vehicle run at 60 KM/hr on the 3 rd gear-shift. The tractive force was zero (Fig.4) and equal to 780 N (Fig. 5). It is clearly seen from both figures that the same trend for the vibration responses is obtained, while the the highest amplitudes arise in both cases in the frequency range up to 1 KHz. This may be attribted to the excitation force generated from the combustion process. On the other hand, the effect of tractive force generated at wheel/roller interface can be observed when comparing the results in Fig. 4 with that in Fig. 5, and it is very small. Fig. 6 shows the results obtained at off-side point for the same conditions as in Fig. 4. For the lack of comparison between the vibration responses in the two points, it can be stated that the vibration behaviour of them are much different, therefore, when these results taken as a guid for redesign or modification they should. be treated separately. The effect of gear-shift at constant vehicle speed can be found from the comparison between Figs. 4 and 7, which indicates that the vibration behaviour of near-side point of measurement at 3 rd gear-shift is higher than that measured at 4 th gear-shift, but still the trend of responses the same.

Road Surface Vibration Results

Having applied the above procedure on the small Saloon vehicle in order to : measure its road surface vibration. Samples from the results obtained are shown in Figs. 8,9,10 and 11. The frequency range used is 200 Hz and the vibration response is presented as vibration acceleration reference to :  $3.16 \times 10^{-4} \text{ m/sec}^2$ . The measuring point was taken at off-side rear suspension. Figs. 8,9 and 10 show the acceleration responses measured at vehicle .



Fig. 9 Vibration response at off-side point for road surface vibration



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Fig. 11 Vibration response at off-side point for read surface vibration

seen that the vibration responses measured at the same conditions are changed from road surface to another, while the peaks arise are lined appr oximately at the same frequencies such as 22 Hz, 45 Hz, 62 Hz, 75 Hz, 125: Hz and 175 Hz. On the other hand, the responses of Asphalt-concrete surface
 (Fig. 9) are slightly higher than that measured for Gravel road surface

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particularly in frequency band of 100 Hz to 140 Hz (Fig. 8), while in the frequency band of 180 Hz to 200 Hz the responses at Gravel road are much higher. The same notice can be found in Fig. 10 (pavement). In Fig. 11, the vibration responses measured at the same vehicle speed of 78 KM/hr for the Asphalt-concrete surface only but at 3rd gear-shift. The results in this figure when compared with that in Fig. 9 they indicate that the measured responses are higher at 3rd gear-shift than that for the 4th gear-shift. This may be attributed to the fact that the engine vibration affects the response of road surface on 3rd gear-shift.

### CONCLUSIONS

- 1. The simulation and measuring systems used in assessing the vibration performance of vehicles are outlined.
- The applications carried out in this study give some insights about the idynamic performance of the vehicles tested due to engine and road surface inputs. These tests need to be increased to cover all vehicle parts.
- 3. A related on-the-road analysis to provide experimental confirmation of the results involved in this study. This, in turn, will verify the control which various primary elements of the vehicle system have on the vibration performance generated.
- 4. A great information on the dynamic performance of vehicles could be obtained by using this technique. These information can be used to provide a means for predicting vibration response levels at the design stage by the finite element dynamic analysis.

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