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Experimental Investigation on Dynamic Properties of Materials

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Abstract—**The dynamic properties of materials are important in various applications such as FEA modeling in crash testing of automotive vehicles. Properties of human liver in crash test can be finding out by natural frequency of silicone rubber as silicone rubber having nearly same properties of human liver. The natural frequencies of any system can be determined experimentally by FRF method using impact hammer. Further, these natural frequencies and FRF function can be utilized to obtain the dynamic stiffness and damping factor of the material. This methodology can be utilized to find out dynamic material properties of soft tissues such as liver, kidney etc. In the field of biomedical engineering it necessary to investigate human organ injury due to high speed impact or collision such as car accident. Smooth sil-910 having dynamic properties closely equal to human liver. So, the properties of human liver can be determined by finding dynamic properties of silicon rubber. Different samples of silicon material are prepared by keeping diameter constant and varying length and keeping length constant and varying diameter. The study of frequency as a function of length and diameter was carried out by using FFT analyzer. Frequency vs Area Ratio and frequency vs length graphs were plotted. As area ratio of specimen increases the frequency of specimen also increases and at certain point although area ratio increases frequency remains constant. Hence, in this case we find minimum area ratio for constant frequency. In second case as the length of specimen increases the frequency decreases and at threshold length it become constant. We can find optimum length for maximum frequency.**

Keywords—dynamic stiffness; damping factor; FRF function; FFT analyzer; FEA modeling; crash testing.

I. INTRODUCTION

It is very important to know dynamic properties of materials in mechanical applications especially where accuracy have prime importance. Applications like noise and vibrations in cars, reliability of long span bridges, efficiency of loudspeakers, accuracy of wafer-steppers, avoid flutter of aircrafts requires high accuracy. So it is essential to find dynamic properties of materials & controlling excessive noise and vibration levels. Now days in automotive industry for testing vehicles human prototype models are used. After impact on human body response from every organ is studied. Liver is important organ, so it necessary to find out natural frequency on which liver can damage. Smooth Sil-910 is material having dynamic properties closely equal to human liver. In this project we are finding different dynamic properties of silicone rubber.

There are number of properties of materials, which effects on the performance of materials under different operating conditions. Most of the time impact tests are carried out at gradual loading for tensile and compressive test on UCM. In automobile sector different impact tests are carried out according to gradual loading, but in actual practice it may be high force impact in case of vehicle accident. To reduce that effect of high force impact there is need to study and investigate effect of those properties. And hence it is very necessary to characterize material properties so we can vary them in desirable manner. In this way we make an attempt to reduce the effect of those undesirable accidental conditions for human safety. Important Dynamic Properties of materials are as given below

a) Dynamic stiffness

It can be simply defined as dynamic force per unit dynamic deflection. Similarly, the well-known static stiffness is the ratio between a static force and the resulting static deflection. The dynamic stiffness is the ratio of Force (frequency) and vibration response. Various rubber-like materials are used as resilient machine elements, with different elastic, damping and also thermo-mechanical properties. The increase of the dynamic stiffness will reduce the vibration response of the system. Hence we must consider the dynamic stiffness property before installing any machine component. e.g. Very intensive source of noise and vibration are tram or railway wheels especially at high speeds of transport. Therefore the modern types of steel railway wheels contain the visco-elastic damping cushioning, which reduce the transfer of noise and vibrations.

Sometimes, people concerned with "vibration analysis "of machinery lose sight of a very simple truth: vibration is merely a response to other conditions in a machine, it is not (and should not be) the fundamental concern for the machinery engineer. Instead vibration should be thought of as nothing more than a ratio of the forces acting on the machine to its stiffness

There are numerous reasons why knowing the Dynamic Stiffness for your machine invaluable:

- Dynamic Stiffness is the relationship between material parameters and measured vibration response.

- Parameter identification provides information for analytical modeling.

- Trending of Dynamic Stiffness can provide valuable information on changes in material parameters.

- Dynamic Stiffness can be used to estimate the dynamic forces acting in a material

Knowledge of your rotor parameters together with an understanding of what they mean in terms of rotor behaviour allows you to minimize the guesswork when diagnosing material problems and proposing solutions.

b) Loss Factor

It is the ratio of loss modulus to storage modulus. The storage and loss modulus in viscoelastic material is the measures the stored energy representing the elastic portion and the energy dissipated as heat representing the viscous portion. For functional requirement material must has less loss factor. To minimize the loss factor we should increased storage modulus or decreased loss modulus

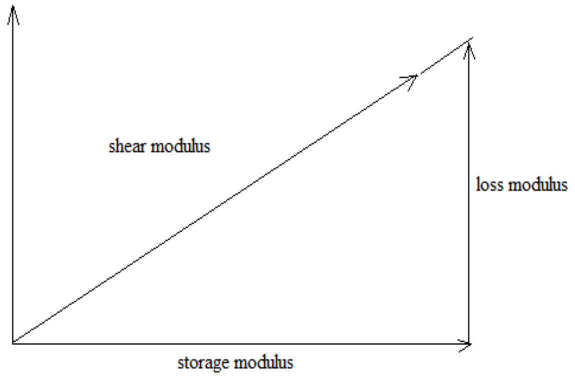

Fig. 1 Graph of loss modulus

c) Dynamic elastic modulus

The modulus of elasticity (= Young's modulus) E is a material property, that describes its stiffness and is therefore one of the most important properties of solid materials. Mechanical deformation puts energy into a material. The energy is stored elastically or dissipated plastically. The way a material stores this energy is summarized in stress-strain curves. Stress is defined as force per unit area and strain as elongation or contraction per unit length. The dynamic elastic modulus is an frequency dependent property. This property allows us to measure the natural frequency of vibrations produced in to the material. Elasticity of a material has great affect on its stiffness. In this way the natural frequency also varies as per the elasticity. Perhaps this property gives us natural frequency variation of material with change in its elasticity.

In this project experimental method based on performing some Frequency Response Function (FRF) measurements on both the bare and damped beams. First of all, the FRF measured on the bare beam is analyzed to determine natural frequencies within the frequency range of interest. Then, measured FRF on the damped beam is analyzed in order to determine the natural frequencies and corresponding modal loss factors of the composite beam. Using the determined natural frequencies of the bare beam, and the natural frequencies and loss factors of the damped beam, Young's modulus and damping level (loss factor) of the damping material are identified at frequencies corresponding to the vibration modes of the damped (composite) beam

Oberst beam test method measures the vibration-damping properties of materials, including loss factor, Young's modulus, and shear modulus. Accurate over a frequency range of 50 to 5 kHz and over the useful temperature range of the material, this test method is useful in testing materials that have application in structural vibration, building acoustics, and the control of audible noise. Such materials include metals, enamels, ceramics, rubbers, plastics, reinforced epoxy matrices, and woods that can be formed to the test specimen configurations. Although the Oberst Beam Test Method is widely used in practice, detailed information about how to perform a successful Oberst beam experiment is quite limited.

Though oberst beam method having ASMT standard then also it having various parameters those affect the results.

Impact hammer test is experimental method, which can find out dynamic properties of soft materials such as ceramics, rubbers, plastics etc. The current methods for characterization of frequency-dependent material properties of human liver are very limited. In fact, there is almost no data available in the literature showing the variation in dynamic elastic modulus of healthy or diseased human liver as a function of excitation frequency. We show that frequency-dependent dynamic material properties of a whole human liver can be easily and efficiently characterized by an impact hammer. The procedure only involves a light impact force applied to the tested liver by a hand-held hammer.

For this project we use impact hammer method. This method is FRF method with include impact of hammer on material and response can be measured on FFT analyzer. Different samples prepared for testing with variation of length & diameters different dynamic properties are found out. The further research in this area can be done to determine the following dynamic properties of material.

1. Dynamic Stiffness
2. Loss Factor
3. Dynamic Elastic Modulus

This methodology can be utilized to find out dynamic material properties of soft tissues such as liver, kidney etc. investigate human organ injury due to high speed impact or collision such as car accident.

II. LITERATURE REVIEW

American Society for Testing and Materials (ASTM) [1] given that oberst beam test method measures the vibration-damping properties of materials, including loss factor, Young's modulus, and shear modulus. Accurate over a frequency range of 50 to 5 kHz and over the useful temperature range of the material, this test method is useful in testing materials that have application in structural vibration, building acoustics, and the control of audible noise. Such materials include metals, enamels, ceramics, rubbers, plastics, reinforced epoxy matrices, and woods that can be formed to the test specimen configurations. This test method addresses the problem of measuring vibration-damping properties that vary greatly with changes in temperature and frequency.

Hasan Koruk and Kenan Y. Sanliturk [2] have studied the Oberst Beam Method used for the measurement of the mechanical properties of damping materials. This method is a classical method based on a multilayer cantilever beam which consists of a base beam and one or two layers of other materials. The base beam is almost always made of a lightly damped material such as steel and aluminium.

Hasan Koruk and Kenan Y. Sanliturk [3] have given detailed information about how to perform a successful Oberst beam experiment is quite limited. In this paper, first, the effects of various parameters in an Oberst test rig, including the amplitude of the excitation, mounting conditions, input excitation type and the length of the test sample, are examined in an attempt to improve the accuracy of the estimated material properties. As it is observed that the electromagnetic effect created by a non- contact exciter can be the most significant source of error in estimated material properties, this paper then presents the results of extensive tests so as to quantify the level of the adverse effects of non-contact electromagnetic excitation. It is found that non-contact electromagnetic exciter creates a stiffness effect that can be modeled as a spring attached between the non-contact exciter location on the Oberst beam and the ground. In contrast to the common belief that the use of non-contact electromagnetic excitation has little drawbacks, it is shown that such excitation can introduce very significant level of errors in identified material properties. This paper also proposes a method for removing the adverse effects of the electromagnetic excitation in order to obtain more accurate material properties for uniform as well as composite beams.

Cagatay Basdogan [3] investigated the dynamic material properties of human and animal livers based on frequency using impact hammer and FFT analyzer. They have characterized dynamic stiffness, loss factor, elastic modulus and storage modulus by conducting an impact test on human livers. Also, results obtained by impact tests are more reliable than that of dynamic tests. He has also obtained dynamic material properties of human and animal livers which are important for diagnosing medical pathologies and developing solutions for them. Time dependent material properties are investigated using dynamic loading tests setup, while frequency dependent material properties were investigated using hand held impact hammer test setup. He also studied that the viscoelastic material properties of soft tissues with implications for liver transplantation and developing solutions of them. And also investigated storage and loss moduli properties as a function of excitation frequency by using impact hammer test setup, while time dependent relaxation modulus by ram and hold experiments.

M. Umut Ozcan et al. [5] studied the frequency-dependent material properties of human liver. In fact, there is almost no data available in the literature showing the variation in dynamic elastic modulus of healthy or diseased human liver as a function of excitation frequency. He show that show that frequency-dependent dynamic material properties of a whole human liver can be easily and efficiently characterized by an impact hammer. The procedure only involves a light impact force applied to the tested liver by a hand-held hammer. The results of our experiments conducted with 15 human livers harvested from the patients having some form of liver disease show that the proposed approach can successfully differentiate the level of fibrosis in human liver.

III. EXPERIMENTAL METHODOLOGY

(a) Instruments required

FFT: Fourier transform is mechanical procedure to obtain a spectrum of a given input signal. A signal which is represented by an equation or a graph or a set of data points with time as an independent variable is transformed in to another equation of graph or set of data points where frequency is the independent variable, by using Fourier transform. A mathematical set of data points can be converted to a spectrum, using Fourier transformation programme in a digital computer. Thus, the method to obtain the spectrum using computer is called as fast Fourier transforms (FFT).

Accelerometer: Accelerometer is an instrument that measures the acceleration of vibrating body. Accelerometers are also used to satisfy accurate measurement of vibration, shock and motion for monitoring, control, and testing applications. Once the acceleration is recorded the velocity and displacement is obtained by integrating. Accelerometers are manufactured as single axis, dual axis or three axis (Triaxial) sensors. Both ceramic and quartz sensing elements are utilized in seismic accelerometer designs. Mostly piezoelectric crystals are used in accelerometers. Piezoelectric crystals are very stiff (i.e. they have high natural frequency, generally 10 kHz to few MHz) and produces a signal proportional to their deformation. However a piezoelectric crystal is capable of generating a measurable signal even for a small deformation. If the signals are very weak amplifier is used to amplify them.

Impact Hammer: Impact hammer features a rugged, force sensor that is integrated into the hammer's striking surface. "Modal Tuning" is a feature that ensures the structural characteristics of the hammer do not affect measurement results. This is accomplished by eliminating hammer resonances in the frequency range of interest from corrupting the test data.

The force sensor serves to provide a measurement of the amplitude and frequency content of the energy stimulus that is imparted to a test object. Accelerometers are used in conjunction with the hammer to provide a measurement of the object's structural response due to the hammer blow. A variety of tips supplied with each hammer permit the energy content of the force impulse to be tailored to suit the requirements of the item under test.

Force sensor: Force sensor contains force sensing resistors (FSR) which are a polymer thick film device which exhibits a decrease in resistance with an increase in the force applied to the active surface. Its force sensitivity is optimised for use in human touch control of electronic devices. FRSs are not a load cell or strain gauge, though they have similar properties. These sensors are ideal for measuring forces without disturbing the dynamics of a test. They can be used to measure both static and dynamic forces. They are thin enough to enable non-intrusive measurement. Force sensor is attached at the front end of an impact hammer to sense the force imparted on a specimen.

(b) Experimental Setup

It consists of following equipments

1. FFT
2. Impact Hammer
3. Accelerometer
4. Silicon sample
5. Preloads

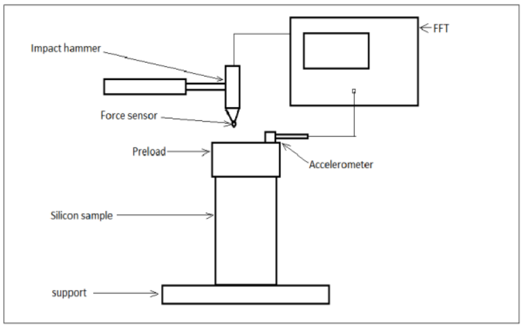

Fig. 2 Experimental Setup layout

- The Force sensor is connected to the FFT through an impact hammer. It converts impact force into analogue signal.
- The accelerometer is of magnetic type and it will be attached on the preload to sense the vibration accelerations.
- Both the Impact hammer and Accelerometer having connections with FFT analyzer. And finally both devices will send the analogue signals to the FFT to get frequency response functions.
- The silicon samples are placed on support and preload is to be on the sample.

(c) Sample preparation

We are using silicon rubber as a sample material for test. Silicon samples have prepared into two forms as below

- Case 1 :- Constant Diameter and varying length
- Case 2 :- Constant length and varying Diameter

Detailed dimensions of silicon samples and preload pieces are shown in following tables with figure. The length of preload is kept constant for all pieces = 20 mm.

Table 1 Dimensions for silicon sample

Case 1	Parameter	1	2	3
Constant Diameter and varying length	Diameter (mm)	25	25	25
	Length (mm)	30	40	50

Silicon Samples for Constant Diameter

Fig.3 Diameter constant and Length varying

Case 2	Parameter	1	2	3
Constant length and varying Diameter	Diameter (mm)	25	30	33
	Length (mm)	50	50	50

Table 2 Dimensions for silicon sample

Silicon Samples for Constant Length

Fig.4 Constant Length and varying Diameter

Table 3 Preload samples

Sr. No.	1	2	3
Area ratio	1:1	1:2	1:2.5
Diameters (mm)	25	12.5	10
	30	15	12
	33	16.5	13.2

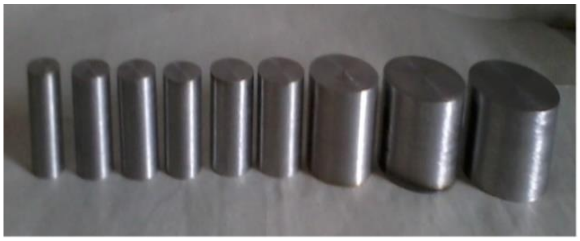

Fig. 5 Preloads of different area ratio

(c)Procedure

- At first all the equipments are arranged as per set up. In first case we make a test on silicon samples of varying length and constant diameter
- When we made a impact on a pre-load which is mounted on a silicon sample with the help of impact hammer.
- At the tip of the impact hammer there is force sensor which senses the force value and it gives idea to give how much forced can be applied on the pre-load to get optimum vibration.
- The natural frequency of the silicon sample plus preload is sensed by accelerometer in terms of acceleration.
- And the signals coming from force sensor and accelerometer is send to FFT analyzer and it gives resonance frequency.

IV. RESULTS AND DISCUSSION

Table 4: Case No. 1- Constant Length, Diameter varying

Sr.No.	Area Ratio	Frequency(Hz)
1	1	10.5
2	2	11.5
3	2.5	12
4	3	12.4
5	3.5	12.8
6	4	13.1
7	4.5	13.1

Frequencies for respective area ratio in case of constant diameter is shown in table no. 4, it shows that after area ratio 4 frequencies remain constant. Whereas table no.5 shows frequencies for respective length of specimen in case of constant length, which shows frequency become constant after length of specimen 80mm.

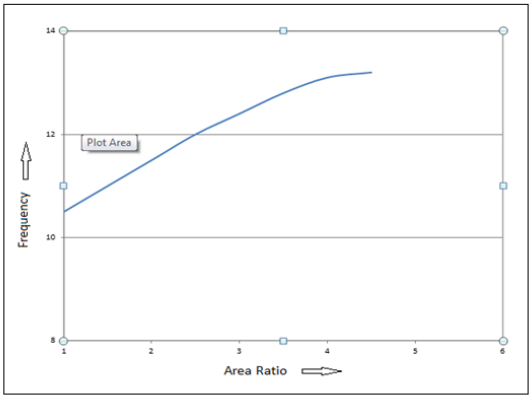

Fig. 6 Graph of Frequency vs Area Ratio

Summary:

From the graph it shows that as area ratio of silicon sample increases the frequency of silicon samples also increases .At certain point area ratio (AR=4) increases frequency remains constant

Table 5: Case No. 2 - Constant Diameter, Length varying

Sr.No.	Length(mm)	Frequency(Hz)
1	20	22.5
2	30	17
3	40	13
4	50	11.4
5	60	10
6	70	9.5
7	80	9.2

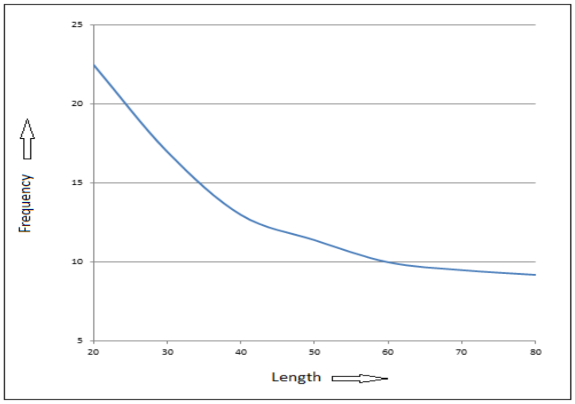

Fig. 7 Graph of Frequency vs Length

Summary:

From graph it shows that as length of silicon sample increases, the frequency of silicon sample decreases at the threshold length (L=80mm) it become constant.

Since the cross sectional areas of the silicon sample in our study experiment were significantly larger than that of the preload used in our experiment, an effective value for the cross sectional area was found with the help of graphs. The value of cross sectional area of silicon sample is four times the preload based on the result obtained in our experiments performed with silicon samples. For the effective length, the threshold length is obtained by the graph (length =80mm). From the case 1 result it shows that with increase in area ratio frequency increases that means material having more stiffness

V. CONCLUSION

From the available literature survey we inspired to study frequency dependent material properties of viscoelastic materials. We decided to test a silicon samples to find out its frequency dependent properties. We carried out tests on different dimensions of silicon samples and have got results from FFT Analyzer. We found that there is nonlinear behavior of material properties against frequency. In this case we have plotted two graphical nature such that Area ratio vs Frequency and Length vs Frequency of silicon samples.

Finally from graphical nature we conclude that as area ratio of specimen increases the frequency of specimen also increases and at certain point although area ratio increases frequency remains constant. Hence, in this case we find minimum area ratio for constant frequency. And in second case as the length of specimen increases the frequency decreases and at threshold length it become constant. We can find optimum length for maximum frequency. As we know that the smooth silicon, which is frequently used in movie industries for modeling Aliens, making mask, and replicating the human parts like arm, hand even face hence we can use this phenomenon in biomedical soft tissues. From this we also study the repose of human liver comparing with silicone rubber during crash test of vehicle.

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