Review on Characterization of Frequency-Dependent Material Properties of Human Liver

Bendre D.R. [1], Prof.Siddharaj S. Allurkar [2], Prof. D.R. Kotkar [3]

Abstract— **The present study is an attempt to take an overview of the work done in the area of characterization of Frequency dependent material properties' of human liver. 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. Dynamic properties of materials like Young's Modulus, Loss Factor, and Natural Frequency are very important for applications where accuracy is prime importance, hence finding dynamic properties of materials is very importance for the applications like cars, oil plant, airplane etc. The properties of material can be finding out by experimental method and FEA. The experimental methods available are very limited so selecting proper method for proper materials is necessary. The study of different properties and behavior of human liver are the main areas of interest of researchers.**

Index Terms— **Dynamic Properties, Young's Modulus, Loss Factor, Natural Frequency, FEA method FRF function; FFT analyzer, crash testing.**

1) Introduction

In mechanical applications it is very important to know dynamic properties of materials especially where accuracy have prime importance. . 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 [1]. Dynamic response of soft tissues to periodic or impact loading is important in many areas of biomechanics and biomedical engineering.Impact hammer test is experimental method, which can find out dynamic properties of soft materials such as ceramics, rubbers, plastics etc.[1]. Accurate characterization of the mechanical properties of soft tissues is important for diagnosing medical pathologies and developing solutions for them [2]. In most of the earlier studies focusing on dynamic material properties, either time- or frequency-dependent material properties have been measured via stress relaxation and dynamic loading experiments, respectively[2].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 [6]. 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 [7]. We investigate the effect of preservation period on the dynamic material properties of bovine liver using a viscoelastic model derived from both impact and ramp and hold experiments [3].

2) Literature review

M. Umut Ozcan, et.al. [1] states that, 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.

Cagatay Basdogan, et.al. [2] 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.

Sina Ocal, et.al. [3] In this article, investigated the effect of preservation period on the dynamic both time and frequency dependent material properties of bovine liver with implications for liver transplantation. On the other hand, the frequency-dependent material characteristics of the same liver samples were measured for different preservation periods using a commercial impact hammer.

Evren Samur, et.al. [4] explained that, The lack of experimental data in current literature on material properties of soft tissues in living condition has been a significant obstacle in the development of realistic soft tissue models for virtual reality based surgical simulators used in medical training. Finally, an inverse finite element solution was developed using ANSYS finite element package to estimate the optimum values of viscoelastic and nonlinear hyperplastic material properties of pig liver through iterations.

Tian Ran Lin, et.al. [5] explained that, Rubber materials have been widely used in the control of structural vibration and sound radiation. It is found that, in general, rubber dynamic properties depend on static pre-load, vibration amplitude, and temperature and excitation frequency. In this paper, a simple experimental method, which adopts impact test, is proposed.

American Society for Testing and Materials (ASTM) et.al. [6] 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.

Hasan Koruk, et.al. [7] has 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.

Kenan Y. Sanliturk, et.al. [8] has 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.

Yanchu Xu, **et.al. [9]** said that, a new method to measure, analyze, and model the dynamic properties of viscoelastic materials is described. The method is based on the vibrating beam technique (ASTM E756) which has been used for determining dynamic complex modulus properties over wide temperature and frequency ranges.

B. S. Ben, et.al. [10] states that methodology for finding material damping properties at higher frequency and at relatively lower amplitudes. The method employs combined Finite element and frequency response for finding the damping characteristics of composite materials, which are used in high frequency applications.

G.Erdoğan, et.el. [11] this paper presents a brief description of a methodology based on the Oberst Beam Method and demonstrates its application for the identification of the dynamic properties of 'self-supporting' and 'non-self-supporting' materials. A unique feature of this work is that the so called Line-Fit Method commonly used in modal analysis of Frequency Response Functions is employed during the process of identification of material properties.

Jean-Luc Wojtowicki, et. al. [12] said that, The Oberst method is widely used for the measurement of the mechanical properties of viscoelastic or damping materials. The application of this method, as described in the ASTM E756 standard, gives good results as long as the experimental set-up does not interfere with the system under test.

Jean-Luc Wojtowicki, et.al [13] said that, The Oberst beam is a classical method for the characterization of damping material based on a multilayer cantilever beam (base beam one or two layers of other materials). The proposed algorithm for the calculation of modal parameters has been specially developed to use a more precise estimation of modal parameters than a simple half power bandwidth method without using advanced modal testing software.

Michal Rak, et.al. [14] that the problem of estimation of a structural loss factor for a beam covered with a viscoelastic layer is addressed in the paper. Thus the values of the identified parameters are not reliable. It has been shown that McDaniel method enables correct estimation of the loss factor within wide frequency range.

Sung Soo Jung, et.al. [15] in this paper an acoustic velocity sensor, micro-flown, was used to monitor the vibration signal in measurements of the resonance frequency, the loss factor, and the dynamic Young's modulus of structural steel and polycarbonate by using a resonance method.

Amy E. Kerdok, et. al. [16] explained that, accurate characterization of soft tissue material properties is required to enable new computer-aided medical technologies such as surgical training and planning. The current means of acquiring these properties in the in vivo and ex vivo states is fraught with problems, including limited accessibility and unknown boundary conditions in the former and unnatural behavior in the latter. This paper presents a new testing method where a whole porcine liver is perfused under physiologic conditions and tested in an ex vivo setting. **Miklos Z Kiss, et.al. [17]** explained that, Mechanical properties of biological tissues are of interest for assessing the performance of electrographic methods that evaluate the stiffness characteristics of tissue. The mechanical properties of interest include the frequency-dependent complex moduli, storage and loss moduli of tissues. Determination of the mechanical properties of biological tissues is often limited by proper geometry of the sample, as well as homogeneity of the stress–strain relationship.

Sun-Yong Kim, et.al. [18] explained that, the dynamic properties of viscoelastic damping materials are highly frequency- and temperature-dependent. Numerical methods of structural and acoustic systems require the mathematical model for these dependencies. The fractional derivative model on damping material has become a powerful solution that describes the frequency-dependent dynamic characteristics of damping materials. The FRFs on the points identical to those measured are calculated using an FE model with the equivalent stiffness approach.

M. Guden, et.al. [19] states that, three distinctly different metal matrix composites have been tested at strain rates from quasi-static to $\approx 3000\ s^{-1}$. It was found that the high strain rate response of each composite was determined primarily by (a) the response of the matrix in the absence of any reinforcement and (b) the damage formation and accumulation processes during deformation. High strain rate behaviour of the short fiber composite was dominated by the matrix behaviour at low strains but by fiber damage at high strains.

O.Danilov, et.al [20] this paper contains an adaptation of Oberst's beam to the assessment of the determination of Young's modulus and loss factor of porous materials. The limits of the proposed method are investigated through the analysis of experimental and numerical results.

Liang Dong, et.al. [21] explained that, High structural damping combined with high stiffness is achieved by negative stiffness elements. Negative incremental structural stiffness occurs when a column with flat ends is subjected to snap-through buckling. Large hysteresis (i.e., high damping) can be achieved provided the ends of the column undergo tilting from flat to edge contact. The column configuration provides high structural stiffness. Stable axial dampers with initial modulus similar to that of the parent material and with enhanced damping were designed built and tested.

Andrew R. Kemper et.al. [22] state that he liver is one of the most frequently injured organs in abdominal trauma. Although motor vehicle collisions are the most common cause of liver injuries, current anthropomorphic test devices are not equipped to predict the risk of sustaining abdominal organ injuries. Consequently, researchers rely on finite element models to assess the potential risk of injury to abdominal organs such as the liver. These models must be validated based on appropriate biomechanical data in order to accurately assess injury risk.

Costin D, et.al. [23] explain that recent statistical studies of fatal injuries showed increases in the ratios of abdominal injuries to head and thorax injuries of 9.6 and 5 times, respectively in newer cars relative to older cars. Therefore, the protection of abdomen in frontal crashes has recently attracted increased attention in the automotive safety community. The liver is one of the most frequently injured abdominal organs in frontal vehicle crashes Therefore, accurate material and failure properties of the liver may help in designing advanced restraint systems based on computer simulations data provided in this study may help in improving the accuracy of human FE models which may help in designing countermeasures for abdominal injury protection.

Yuan-Chiao Lu, et.al. [24] state that the effect of tissue preservation by means of freezing on the material properties of abdominal tissues remains unknown. The goal of this study was to investigate the influence of frozen storage time on the material responses of the liver parenchyma in tensile loading. The current study quantified the material and failure response of fresh and d preserved liver parenchyma specimens in tensile loading at various strain rates. Significant changes in the failure strain were observed between previously frozen liver parenchyma samples and fresh samples at both global and local levels (po0.05). In addition, nonlinear and viscoelastic characteristic s of the liver parenchyma were observed for both fresh and preserved samples.

Hang Wang, et. at. [25] gives the dielectric properties of human liver were determined by characterization of tissue absorption and coupling of electromagnetic energy in the electromagnetic field. In this study the ex-vivo dielectric properties of human hepatocellular carcinoma (well and moderately differentiated), liver hemangioma, hepatic fibrosis (stages S1 and S2), and normal liver tissue were measured and analyzed over the frequency range of 10 Hz to 100 MHz. The data can contribute to developing bioelectric applications for tissue diagnostics and creating more accurate computer models for medical applications.

Andrew R. Kemper et.al. [26] state that Motor vehicle collisions commonly result in serious life threatening liver injuries. Although finite element models are becoming an integral tool in the reduction of automotive related liver injuries, the establishment of accurate material models and tissue level tolerance values is critical for accurate injury risk assessment. This study presents a total of 51 tension tests performed on human liver parenchyma at various loading rates in order to characterize the viscoelastic and failure properties of human liver.

Matthew Wadham-Gagnon, et.al. [27] explain that a review of the general mechanics of rubber was undertaken in this work which led to a better understanding of the assumptions implied in using hyperelastic models to predict the behaviour of this particular material. The methods employed to quasi-statically characterise a rubber compound in uniaxial, planar and equi-biaxial tension were discussed. Limitations of the hyperelastic models with respect to the characterization data were identified while applying the curve-fitting tools available in ANSYS

B.R. Thapa, et.al. [28] explain that Liver function tests (LFT) are a helpful screening tool, which are an effective modality to detect hepatic dysfunction. Since the liver performs a variety of functions so no single test is sufficient to provide complete estimate of function of liver. Often clinicians are faced with reports that do not tally with the clinical condition of the patient and they face difficulty in interpreting the LFT. An attempt is being made to study and understand the LFT and simplify their interpretation with algorithms.

Zorion Kareaga Laka, et.al. [29] state that The final objective of the present work is the accurate prediction of the dynamic stiffness behaviour of complex rubber parts using finite element simulation tools. For this purpose, it becomes necessary to perform a complex rubber compound material characterisation and modelling work; this needs two important previous steps. These steps are detailed in the present document together with a theoretical review of viscoelastic visco-elasto-plastic models for elastomers.

Marek Jaśkiewicz, et.al. [30] explain that the paper presented different versions of dummies which are selected depending on the realized collision. They very well reflect the characteristics of the human body. They are made of good quality materials and have dozens of sensors performing various measurements. This allows us to make a careful analysis of injury under certain delays. This gives a complete picture of the damage to the human body which occurs during different types of accidents at given speeds. These kinds of dummies are also used to reproduce complex road accidents. Modern solutions make it possible to use a dummy in seated and standing positions.

3) EXPRIMENTATION

We present a new approach based on impact test for the characterization of frequency-dependent material properties of a 'whole" organ having a variable cross-sectional area and length. The commercial measurement devices and approaches for the same purpose are typically designed to work with small samples of known geometry in a laboratory environment. Hence, our approach can be potentially used in in vivo experiments to determine the liver material properties of an organ in place [1]. In this experiments, an impulse excitation force is applied to the cylindrical pre-load (radius = 25 mm, weight = 400 gram) placed on top of the specimen by the impact hammer (PCB Piezotronics Inc., Model 086C03, sensitivity is 2.1 mV/N) equipped with a force sensor shown in fig.1. As suggested by the manufacturer, a soft tip and an extender mass were utilized for better response at low frequencies. The impulse response of the specimen was measured by a piezoelectric accelerometer (PCB Piezotronics Inc., Model 333B30, sensitivity is 101.2 mV/g, where g is the gravitational acceleration, range is 0.5–3000 Hz) attached to the pre-load using a thin film of adhesive wax. As suggested by the manufacturer, five measurements were taken from each test specimen and then the average values were used in the analysis. [1].

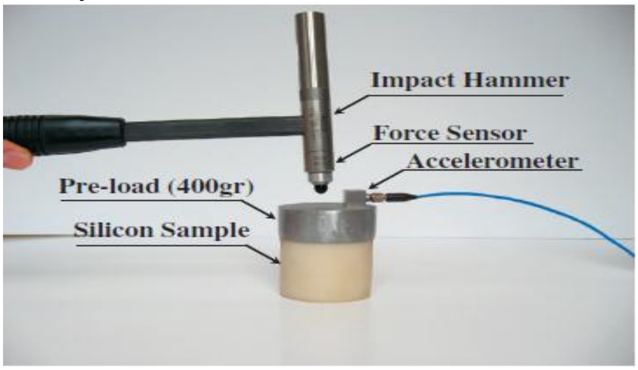

Fig.1 The components of the measurement system [1]-[3]

The accelerometer and the force sensor were connected to a dynamic signal analyzer (Data Physics Corporation, type SignalCalc Mobilyzer) for data processing. The FRF was obtained by taking the Fourier transform of the impulse response. In dynamic loading test, the same FRF is obtained by the frequency sweep method (i.e. small periodic strains are applied to the specimen and its force response is measured for a range of frequencies).

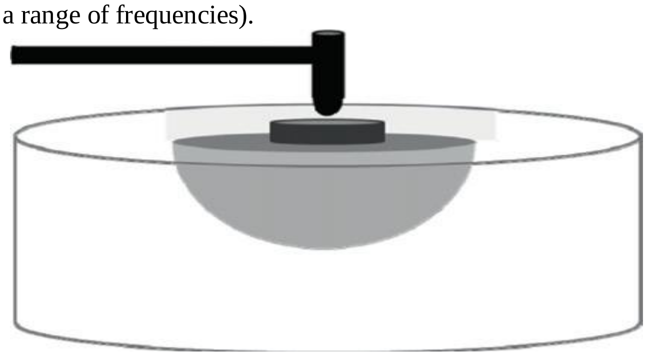

Fig. 2 The propagation of impact load on a large sample [1]

Fig. 3 The family of silicon samples used in our experiments [1]

Compared to the dynamic test, the impact test is more practical and the measurement time is much shorter. Moreover, the results obtained by the impact test are as reliable as the ones obtained through the dynamic loading test.

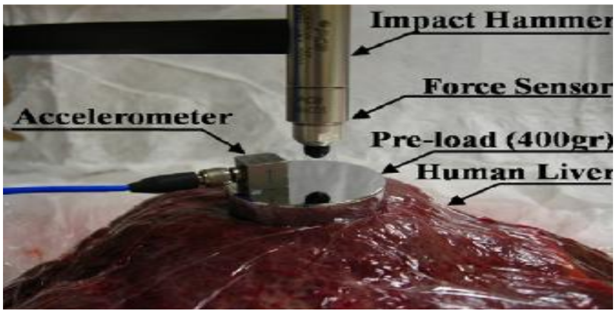

Fig. 4 The dynamic material properties of human liver were measured as a function of frequency by an impact hammer [1]-[2]

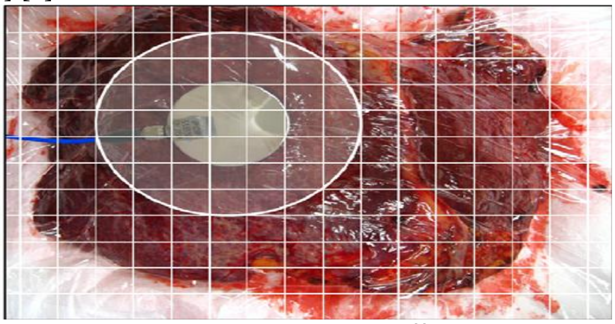

Fig. 5 The impact load in our set-up is affective only within the surface area of liver [1]

OBM is the classical method for the characterization of damping materials 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. This method is useful in testing materials such as metals, enamels, ceramics, rubbers, plastics, reinforced epoxy matrices and woods. The mentioned multilayer cantilever beam is given in Fig.6 the root of the beam is wedged into a heavy and stiff clamping system.

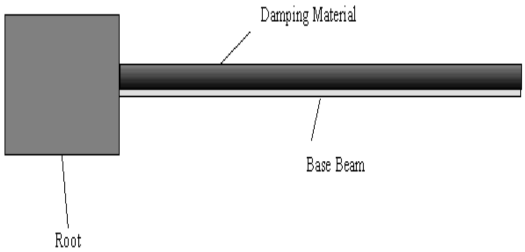

Fig. 6 cantilever beam used in the oberst beam method [7]

Oberst beam method is 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 analysed to determine natural frequencies within the frequency range of interest. Then, measured FRF on the damped beam is analysed 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. The use of contacting transducers is not recommended in OBM. The use of contacting transducers adds damping and mass to the beam as a result of the attachments of the excitation and response sensors and this significantly reduces the quality of the results in Oberst beam method. [7]

As shown in Fig. 7, the Oberst test rig used in this study consists of a cantilever beam mounted on a test stand, an exciter, a response sensor and associated data acquisition and signal processing system. Both the response sensor and the exciter used in this test rig are of non-contact type. The response sensor is a velocity-sensitive magnetic transducer. The exciter, on the other hand, is an electromagnetic type located at the free end of the beam. Measurement procedure for acquiring a Frequency Response Function (FRF) using the Oberst test rig is illustrated in Fig. 8. Furthermore, 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. [8]- [9]

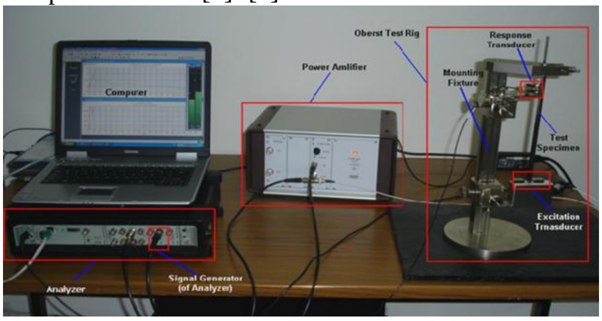

Fig. 7 Oberst test rig [8]

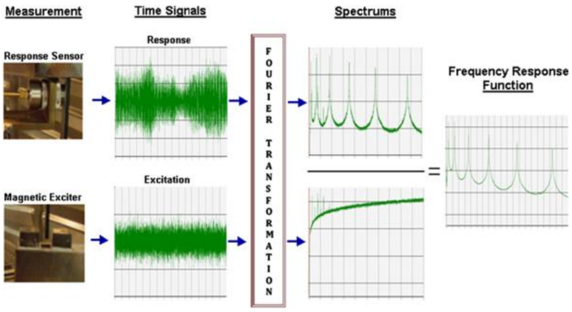

Fig. 8 Illustration of a typical FRF measurement using Oberst test rig. [8]

4) Mechanical characterization

a) Dynamic stiffness: Dynamic Stiffness is the relationship between material parameters and measured vibration response. 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.[1]

b) Loss Factor: It is the ratio of loss modulus to storage modulus. In viscoelastic material the storage and loss modulus the stored energy is measures representing the heat as representing the viscous portion the elastic portion and the energy dissipated. For functional requirement material must has less loss factor. To minimize the loss factor we should increased storage modulus or decreased loss modulus. [1]

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 energy stored in material is summarized in the way of stress-strain curve.[1]

d) Linear static response: An effective shear and elastic moduli of pig liver was estimated from the static indentation data using the linear elastic contact theory and the small deformation assumption.[5]

e) Viscoelastic response: The history of stress response of viscoelastic materials is characterized by shear relaxation function G(t), which can be represented by the Prony series. [5]

f) Inverse finite element solution: The characterization of material properties based on experimental data is considered as the inverse problem. We used a finite element modeling package (ANSYS) and its optimization toolbox to solve the inverse problem. To develop the inverse solution, a finite element model of the liver was developed. The liver tissue around the contact region was modeled as a semi-infinite elastic half space using 2D axisymmetric finite elements (PLANE183) having hyperelastic, viscoelastic, large deflection, and large strain capabilities. [5]

5) Conclusion

Accurate characterization of soft tissue material properties is required. The frequency dependent material properties and different experimental methods used for accurate measurement of material properties have been discussed. The experimental methods available are very limited so selecting proper method for proper materials also studied. The Impact hammer method is more suitable method than the Oberest beam method. This study may help in improving the accuracy of human FE models which may help in designing countermeasures for abdominal injury protection for human liver and organs in frontal vehicle crashes. The different version of dummies which are made of quality materials helps to make a careful analysis of injury occurs during different types of accidents of human liver and body.

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REFERENCES

[1] M. Umut Ozcan, Sina Ocal, Cagatay Basdogan, Gulen Dogusoy , YamanTokat" "Characterization of frequency-dependent material properties of human liver and its pathologies using an impact hammer" research paper publish in science direct on 1 July 2010,pp.45-52.

[2] Cagatay Basdogan, "Dynamic Material Properties of Human and Animal Livers" College of Engineering, Koc University, 34450, Istanbul, Turkey, 2012, pp.1-13.

[3] Sina Ocal, M. Umut Ozcan, Ipek Basdogan, Cagatay Basdogan "Effect of Preservation Period on the Viscoelastic Material Properties of Soft Tissues With Implications for Liver Transplantation" Journal of Biomechanical Engineering, october 2010, Vol. 132. pp-101007-7.

[4] Evren Samur , Mert Sedef , Cagatay Basdogan, Levent Avtan, Oktay Duzgun, "A robotic indenter for minimally invasive measurement and characterization of soft tissue response, College of Engineering, Koc University, Istanbul, Turkey,7 April 2007,pp.361-373.

[5] Tian Ran Lin, Nabil H. Farag , Jie Pan, "Evaluation of frequency dependent rubber mount stiffness and damping by impact test" School of Mechanical Engineering, The University of Western Australia, 35 Stirling Highway, Crawley, WA 6009, Australia, 8 December 2004,pp.829-844.

[6] American Society for Testing and Materials (ASTM), 1916 Race St Phlladelphia, Pa 19103, Reprinted from the Annual Book of ASTM Standards." 1993, pp.1-3.

[7] HasanKoruk&Kenan Y. Sanliturk, "On Measuring Dynamic Properties of Damping Materials Using Oberst Beam Method", Proceedings of the ASME 2010 10th Biennial Conference on Engineering Systems Design and Analysis ESDA 2010 July 12-14, 2010, Istanbul, Turkey"2010, pp.1-8.

[8] Hasan Koruk & Kenan Y. Sanliturk, "Identification and removal of adverse effects of non-contact electromagnetic excitation in Oberst Beam Test Method", research paper publish in science direct on 2 March 2012, pp.274-295.

[9] Yanchu Xu and Ahid Nashif, "Measurement, Analysis and Modelling of the Dynamic Properties of Materials" sound and vibration July 1996, pp.20-23.

[10] B. S. Bena, B. A. Benb, Adarsh K , K. A. Vikram and Ch.Ratnamd," Damping measurement in composite materials using combined finite element and frequency response method" Department of mechanical engineering, S.V.P Engineering College, Visakhapatnam, India, 530003,pp.87-89.

[11] G.Erdogan, F.Bayraktar, K.Y.Sanliturk, "measurement of dynamic properties of materials", published in the 32nd International Congress and Exposition on Noise Control Engineering Jeju International Convention Center, Seogwipo, Korea, August 25-28, 2003,pp.1-8.

[12] Jean-Luc Wojtowicki, Luc Jaouen, Raymond Panneton, "a new approach for the measurement of damping properties of materials using the Oberst beam", review of scientific instruments volume 75, number 8,2004,pp.2569-2574.

[13] Jean-Luc Wojtowicki "Oberst Beam Excitation Using Piezo Electric Actuators" published in From Acoustics Week in Canada 2000/De l 'acte semaine candienne d 'acoustique 2000, pp.41-42.

[14] Michal Rak, Mohamed Ichchou, Jan Holnicki-Szulc, "Identification of Structural Loss Factor from Spatially Distributed Measurements on Beams with Viscoelastic Layer" Journal of Sound and Vibration,2007,pp.16-26.

[15] Sung Soo Jung, Yong Tae Kim, Yong Bong Lee, "Measurement of the Resonance Frequency, the Loss Factor, and the Dynamic Young's Modulus in Structural Steel and Polycarbonate by Using an Acoustic Velocity Sensor" Journal of the Korean Physical Society, Vol. 49, No. 5, November 2006, pp.1961-1966.

[16] Amy E. Kerdok ,Mark P. Ottensmeyer, Robert D. Howe, "Effects of perfusion on the viscoelastic characteristics of liver" , Harvard University Division of Engineering and Applied Sciences, 9 Oxford St., Room 312 60 Oxford St., Cambridge, 8 July 2005, pp.2221-2231.

[17] Miklos Z Kiss, Tomy Varghese, and Timothy J Hall,"Viscoelastic characterization of in vitro canine tissue" ,Department of Medical Physics, 1300 University Avenue, University of Wisconsin, Madison, WI 53706, USA, 2004, pp.4207-4218.

[18] Sun-Yong Kim, Doo-Ho Lee, "Identification of fractional-derivative-model parameters of viscoelastic materials from measured FRFs", Journal of Sound and Vibration 324, 2009, pp.570-586.

[19] M. Guden, I.W. Hall, "Dynamic properties of metal matrix composites: a comparative study", Materials Science and Engineering A242, 1998, pp.141-152.

[20] O. Danilov; F. Sgard; X. Olny, "Oberst beam as a tool for complex young's modulus measurement of porous materials", Experimental and theoretical studies of vibrating systems, pp.1-6

[21] Liang Dong, Roderic Lakes, "Advanced damper with high stiffness and high hysteresis damping based on negative structural stiffness", International Journal of Solids and Structures, 2013, pp.2416-2423.

[22] Andrew R. Kemper, Anthony C. Santago, Joel D. , "Effect of Strain Rate on the Material Properties of Human Liver Parenchyma in Unconfined Compression", Journal of Biomechanical Engineering, october2013, Vol. 135,pp.1-8.

[23]Costin D.Untaroiun, Yuan-ChiaoLu, "Material characterization of liver parenchyma using specimen-specific finite element models", journal of the mechanical behavior of biomedical materials 26 (2013) pp.11–22.

[24] Yuan-ChiaoLu, Andrew R .Kemper, Costin D. Untaroiu, "Effect of storage on tensile material properties of bovine liver", journal of the mechanical behavior of biomedical materials 29 (2014) pp.339–349.

[25] Hang Wang, Yong He, Qingguo Yan, "Dielectric properties of human liver from10Hz to 100MHz: normal liver, hepatocellular carcinoma, hepatic fibrosis and liver hemangioma", Bio-Medical Materials and Engineering 24 (2014) pp.2725–2732.

[26] Andrew R. Kemper, Anthony C. Santago, Joel D. Stitzel, "biomechanical response of human liverin tensile loading," Virginia Tech - Wake Forest University, Center for Injury Biomechanics,pp.1-12.

[27] Matthew Wadham-Gagnon, "Hyperelastic Modelling of Rubber Behaviour in Finite Element Software," Department of Mechanical Engineering Mc Gill University Montreal, Quebec, Canada August 2006, pp.1-143.

[28] B.R. Thapa, Anuj Walia, "Liver Function Tests and their Interpretation," Indian Journal of Pediatrics, Volume 74, July, 2007, pp.663-671.

[29] Zorion Kareaga Laka, Lea Artibai Ikastetxea S. Coop., "Dynamic Stiffness and Damping Prediction on Rubber Material Parts, FEA and Experimental Correlation", London Metropolitan University, July 2016, pp.1-314.

[30] Marek Jaśkiewicz, Darek Więckowski, "Overview and analysis of dummies used for crash tests." Scientific Journals, Maritime University of Szczecin, 2013, 35(107) pp. 22–31.

[31] P. Hofer, A. Lion, "Modelling of frequency-and amplitude-dependent material properties of filler reinforced rubber" Journal of the Mechanics and Physics of Solids 57(2009), pp.500–520.

[32] Cagatay Basdogan, Mehmet Ayyildiz, "Challenges in Characterization of Soft Tissue Material Properties", College of Engineering, Koc University, İstanbul, Turkey, IEEE world haptics June 2015, pp.1-18.

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