The International Journal of Engineering And Science (IJES)
||Volume|| 2 ||Issue|| 01 ||Pages|| 194-200 ||2013||
ISSN: 2319 – 1813 ISBN: 2319 – 1805

An Experimental Study of Automotive Disc Brake Vibrations

[1]Amr M. M. Rabia, [2]Nouby M. Ghazaly,[3]M. M. M. Salem,
[4]Ali M. Abd-El-Tawwab

Automotive and Tractor Eng. Dept., Minia University, El-Minia - 61111, Egypt

ABSTRACT

Friction-induced vibration of disc brakes is a topic of major interest and concern for the automotive industry. Customer complaints result in significant warranty costs yearly. In the present paper, a detailed experimental study of the disc brake vibration is performed on a simplified brake dynamometer. The preliminary brake dynamometer consists of three subsystems, namely driving unit, braking unit and measurement faciliti es. There are approximately twenty seven vibration tests are conducted at various operating conditions such as different brake-line pressure and disc speeds. It is observed that the peak value of the pad vibration amplitude emanates from all tests are dominant at frequency of 4.4 kHz. It is also found that the vibration level decreases with the increase of sliding speed. Moreover, it is observed that the vibration level decreases with the increases of applied pressure.

Keywords - *Brake dynamometer, friction induced vibration, automotive disc brake.*

Date of Submission: 29, December, 2012 ⟺ Date of Publication: 11, January 2013

I. INTRODUCTION

Research into understanding brake noise and vibration has been ongoing over the last 50 years. Initially drum brakes were studied due to their extensive use in early automotive brake systems. However, disc brake systems have been common place on passenger vehicles since the 1960s and are used more extensively in modern vehicles. Discomfort from the disc brake vibration is a major concern in the developing of brake systems and friction materials. The friction materials are required to provide a stable friction coefficient, a low vibration and wear rate at various operating conditions. Friction material must also be compatible with the rotor material in order to reduce its extensive wear, vibration, and noise during braking. All of these requirements need to be achieved at a reasonable cost and minimum environmental load [1].

Although there are numerous publications and a great deal of effort devoted to understanding and correcting brake noise and vibration issue, there is still not a high fidelity model of the brake noise and vibration source. References [2-4] provide some insight into the brake noise and vibration state-of-the-art. Research on the brake noise and vibration has been conducted using theoretical, experimental and numerical approaches. The experimental method is usually taken to be the most scientific of all methods. Experimental approaches have been used to measure the brake frequencies and vibration levels for the system at different operation conditions to verify possible solutions that can significantly reduce vibration [5].

Experimental approaches using brake dynamometers or on-road tests have been widely used to examine the brake vibration, to investigate the effects of different parameters and operating conditions, to understand the characteristics of the brake system during vibration event and to verify possible solutions that can eliminate or reduce the vibration occurrence. There are two designs for the brake noise dynamometer. The first design is an inertia-type brake dynamometer that has flywheel attached to it [6,7]. The second design is a drag-type brake dynamometer that can only test brake vibration at a constant speed [8-12]. The advantage of brake noise dynamometer is that it provided a means of tight experimental control. Pad or rotor temperature, brake pressure, brake torque, and their associated ramp rates are all parameters that can be monitored precisely [13].

It has been recognized that friction and vibration have a mutual influence [14-16]. Friction of brake pads is found to be highly dependent on a number of factors like pressure, temperature and sliding velocity [17]. Friction generates vibration in various forms, while vibration affects friction in turns. A number of researchers have used the term “feedback” in studies involving friction-vibration relations. If one views the effect of frictional contact on the structural behavior of a mechanical system as the first effect then it has been shown that the vibration behavior of the mechanical system will in turn effect the frictional contact; the system feedback on friction [18].

The motivations of this paper are to construct a laboratory drag-type brake dynamometer and evaluate its performance. To conduct a series of tests under different operation conditions of disc speed, applied pressure and brake torque. Furthermore, evaluation of the relation between operation parameters and vibration amplitude which is generated based on friction between the disc and the brake pads.

II. EXPERIMENTAL METHOD

The main objective of the current test rig (simplified dynamometer) is to enable the measurement of vibration of the brake system induced by friction between disc and pads. A dynamometer is designed to provide the necessary disc rotation speed and reaction torque to the brake application. It can be divided into three main groups: the driving unit, the braking unit and the measurement facilities. Fig. 1 shows a photo of the test rig with its different units.

The driving unit consists of an a.c. motor of 14.9 KW and 1500 rpm, that rotates the driving shaft at different rotating speeds. This is achieved with the help of a manual gearbox in first step of reduction speed and four different pulleys in the second step. The main goals of this subsystem to provide the adequate rotational speed of the disc brake. The braking unit comprises the front disc brake assembly of a passenger car. It is composed of the brake ventilating disc with its floating caliper. A hydraulic jack is used to apply an adequate pressure. Approximately 20 bar of hydraulic pressure is sufficient to produce the maximum torque. The measurement facilities including suitable instruments to measure the following: Rotating speed (tachometer), Actuating pressure (a pressure gauge), Caliper acceleration (accelerometer and charge amplifier), temperature (infrared thermometer) and tangential force (load cell).

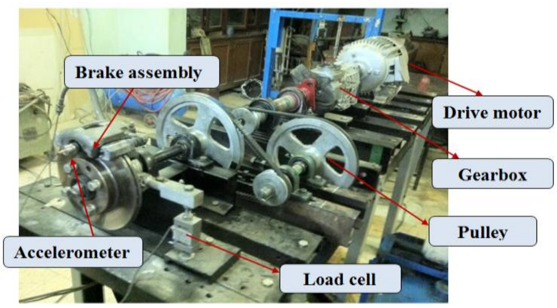


Fig. 1: Schematic diagram of a brake dynamometer

III. EXPERIMENTAL PROCEEDING

Vibration events are recorded at three vehicle speeds 10.75, 17 and 20.8 km/hr, set from the gearbox reduction ratio and pulleys reduction and measured by speed tachometer. Different brake pressure in the range 2.5 to 20 bar is controlled manually by jack screw and temperature is measured by infrared thermometer between 50 ˚C to 70 ˚C through all vibration tests. Four-channels data acquisition system is used to monitor tangential braking force and output data from the accelerometer located at the finger pad through two channels. The signal from the accelerometer is fed to the data acquisition signal through a B&K charge amplifier. The acquired signals are transferred to a computer in digital form for storage and further analysis.

IV. VIBRATION FREQUENCY ANALYSIS

The choice of the analysis domain plays an important role in the successful outcome of the analyses. In real applications, the measured voltage signals of accelerometers are complex waveforms that obtain time domain signals which gave a detailed of understanding vibration pattern. Basically there are two types of vibration pattern exhibit by a vibrational structure either limit cycle or harmonic cycle. To easily compare between vibration amplitudes at different operation conditions, frequency domain signal is preferred analysis. Hence, it must be converted from the time domain to the frequency domain mathematically using Laplace, Z-, or Fourier transforms. Fourier analysis is the most common for this application because it obtains the values of vibration amplitude for each frequency in a signal.

In this study, a Fast Fourier Transform (FFT) using MATLAB is produced for each data channel to produce Power Spectrum Density (PSD) which useful in estimation of the vibration frequency. The measured vibration signal under no load operation shows no (negligible) peak of vibration amplitude due to the driving system. Therefore, the measured vibration signals are due to the interaction between the disc and the brake pads. Fig. 2(a) is one example of time domain data obtained from test brake pad that recorded by accelerometer where vibration harmonic cycle occurred at applied pressure in the range 2.5-20 bar and vehicle sliding speed 10.75, 17 and 20.8 km/hr. Fig. 2 (b) shows the Power Spectral Density of the peak vibration as a function of applied pressure.

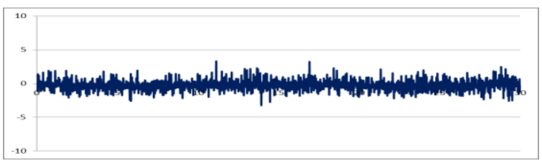


Fig. 2(a): Time Domain data of accelerometer

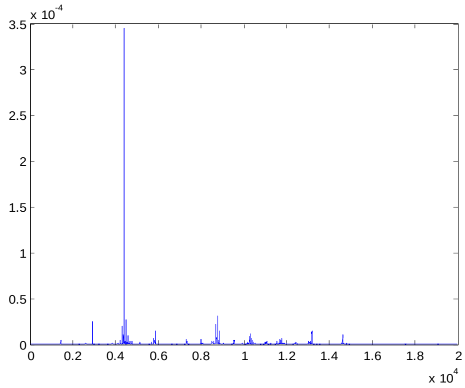
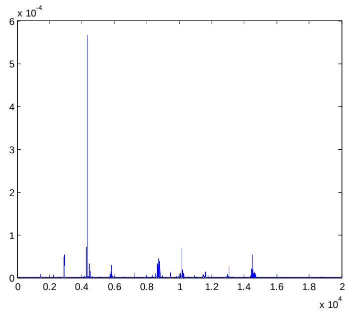


Fig. 2(b): Frequency Domain data of FFT

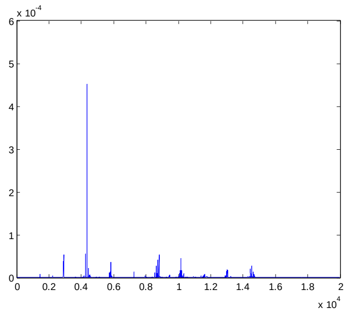
V. RESULTS AND DISCUSSION

In this study, twenty seven vibration tests are conducted at various operating conditions (nine different pressures and three sliding speeds). The experiments are carried out using new disc brake assembly. Vibration frequencies are captured through accelerometer and analyzed using FFT. It is found that that all the peaks in the vibration frequencies do not shift with different operation conditions and are dominated at 4.4 kHz as shown in Fig. 3(a-c). As stated by Smyth and Rice in paper [19], that the vibration dependence on sliding speed should not affect the frequency content, but only increasing the overall level of the vibration, which is verified for the current study.

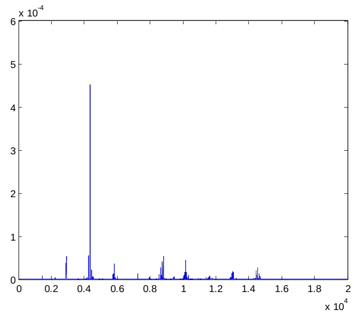
In Fig. 3(a-c), the vertical axis represents the vibration amplitude PSD in $(m/s^2)^2$/Hz and horizontal axis for frequency in Hz. It is observed that vibration amplitude was not similar at every test. Therefore, all the PSD data from each channel at every test were analyzed individually as to define either the existing of vibration event or not.



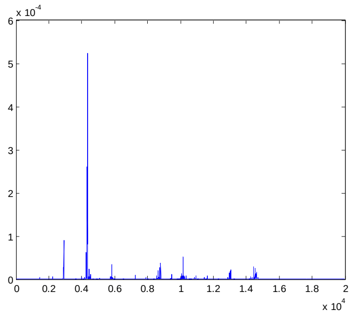
V=10.75km/hr and P=2.5 bar



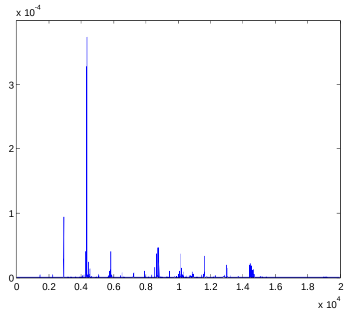
V=10.75km/hr and P=5 bar



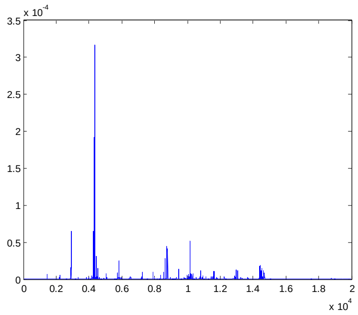
V=10.75km/hr and P=7.5 bar



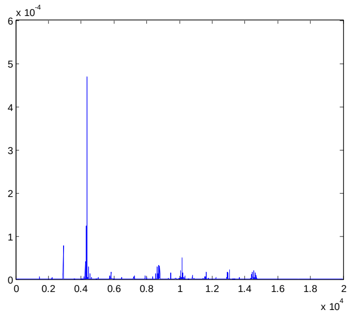
V=10.75km/hr and P=10 bar



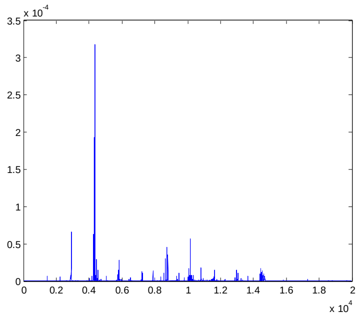
V=10.75km/hr and P=12 bar



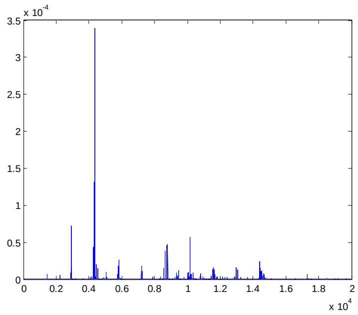
V=10.75km/hr and P=14 bar



V=10.75km/hr and P=16 bar



V=10.75km/hr and P=18 bar



V=10.75km/hr and P=20 bar

Fig. 3(a) Effect of applied load on vibration at vehicle speed of 10.75km/hr

Note: vertical axis represents the vibration amplitude PSD in $(m/s^2)^2$/Hz and horizontal axis for frequency in Hz.

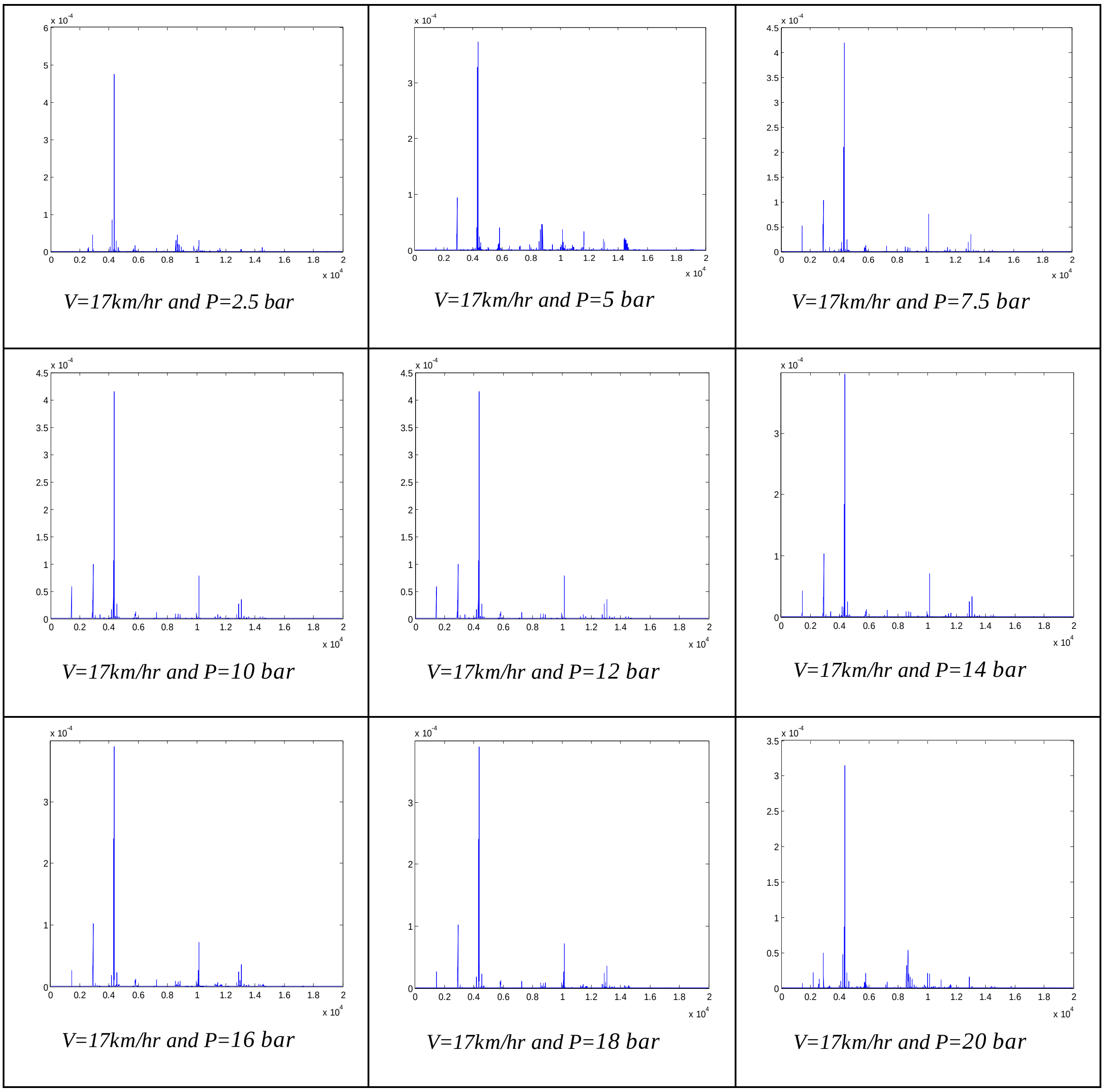


Fig. 3(b) Effect of applied load on vibration at vehicle speed of 17km/hr.

Note: vertical axis represents the vibration amplitude PSD in $(m/s^2)^2/Hz$ and horizontal axis for frequency in Hz.

VI. INFLUENCE OF APPLIED LOAD VARIATIONS

A series of tests at different pressure levels (2.5 to 20 bar) are carried out to investigate the effect of applied pressure towards vibration of brake pads at three different sliding speeds. From the results shown above in Fig. 3, it can be seen that the maximum vibration amplitude occurs at a frequency of approximately 4.4 kHz. The data obtained from the vibration amplitude are plotted against the applied force as shown in Fig. 4(a-c) at three different speeds 10.75, 17 and 20.8 km/hr respectively, it can be observed that with an increase in the applied pressure from 2.5 to 20 bar the vibration levels decreases. It can be observed that at very low applied pressure, disc and pads are barely touching and less friction damping generation between them. In addition, as the applied pressure starts to increase, the disc comes into contact with the pads and the system damping starts to increase (friction damping) due to compressibility of friction materials of the pads and the system rigidity is decreased results in a reduction of the vibration amplitudes as shown in Fig 4(a-c). This experimental result seems to agree with the previous findings presented in paper [20].

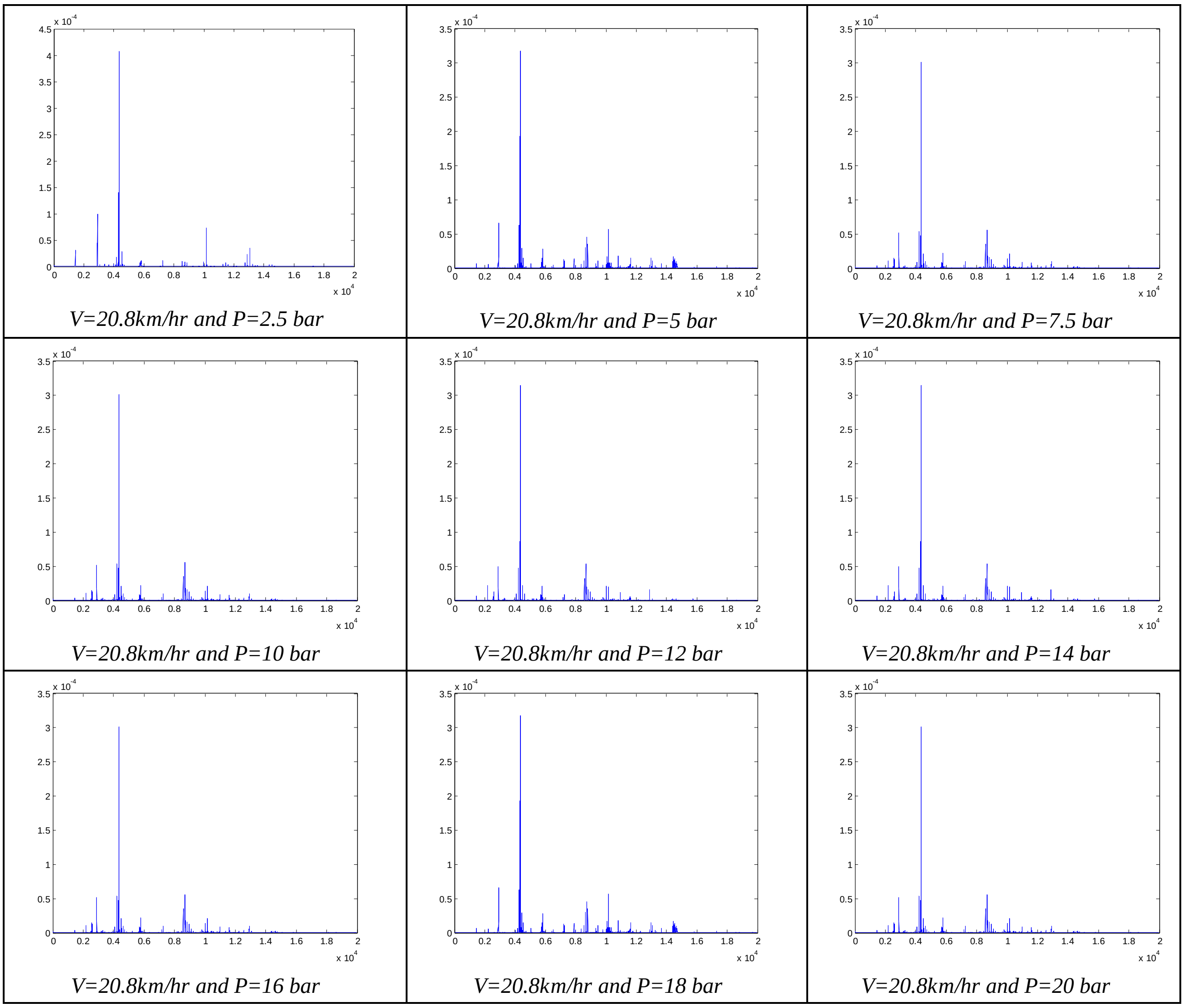


Fig.3(c) Effect of applied load on vibration at vehicle speed of 20.8km/hr.
Note: vertical axis represents the vibration amplitude PSD in $(m/s^2)^2/Hz$ and horizontal axis for frequency in Hz.

VIII. EFFECT OF VEHICLE SPEED

To investigate the influence of the vehicle speed, vibration measurements for three different sliding speed 10.75, 17, and 20.8 km/hr, temperature range 50-70 C° and different applied pressure range 2.5 to 20 bar are conducted. From the results shown in Fig. 5, it can be seen that the increase of the sliding speed decreases the vibration amplitude at different values of applied pressure. It is opinion of the authors that this behaviour is the reason why automotive vibration frequently occurs at low velocity. This result agree with the previous findings presented in numerical paper by Baillet et al. [21] and experimental research as reported in [22]. It has been found that vibration amplitude decreases linearly with disk velocity up to a maximum value and then stays approximately constant when disk velocity increases.

Fig. 4(a) Effect of applied load on vibration at 10.75km/hr.

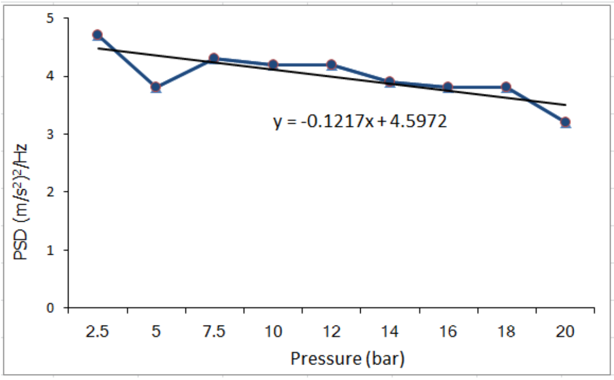
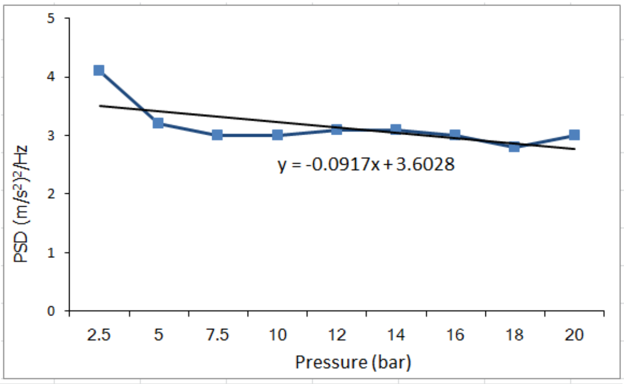


Fig. 4(b) Effect of applied load on vibration at 17km/hr.



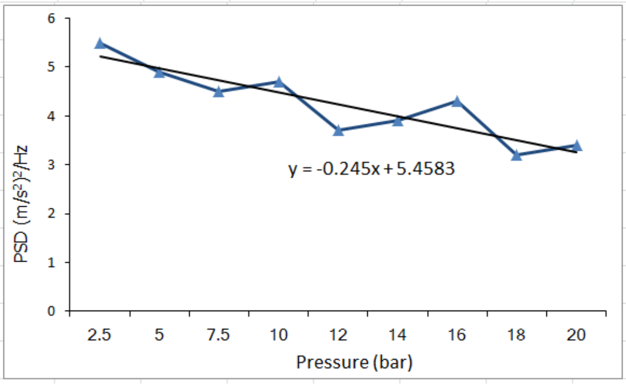
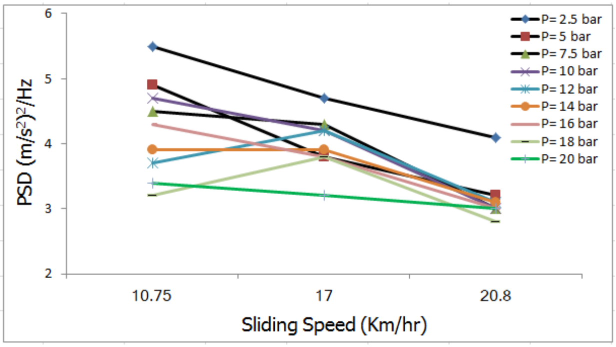


Fig. 4(c) Effect of applied load on vibration at



20.8km/hr.

Fig. 5 Effect of speed on vibration at different pressure.

IX. Conclusion

The experimental study of friction induced and vibration is carried out for automotive disc brake assembly of a passenger car using brake dynamometer. The dynamometer is designed by the author for the purpose of measurements of brake vibration generated by friction. Various operating conditions approximately twenty seven vibration tests are applied to the disc brake assembly. It is concluded that the peak value of the pad vibration amplitude emanates from all tests are dominant at frequency of 4.4 kHz. Moreover, the vibration amplitude is dependent on the brake pressure and the vehicle speed. It is also found that the vibration level decreases with the increase of sliding speed. Furthermore, it is shown that the vibration level decreases with the increases of applied pressure. Evidently, it is possible to investigate the effects of friction-induced vibration in a vehicle using this dynamometer.

Acknowledgements

The authors would like to thank the FAW industry Group, manufacturing and trading of friction products in Egypt and Minia University for their continuous support in the research work.

References

[1]K.W. Hee, and P. Fılıp, Performance of Ceramic Enhanced Phenolic Matrix Brake Lining Materials for Automotive Brake Linings, *Wear, 259*, 2005, 1088–1096.

[2]I. Wallaschek, K-J, Jach, and P.A. Mody, Survey of the Present State of Friction Modeling in the Analytical and Numerical Investigation of Brake Noise Generation, *Proceeding of ASME Vibration Conference,* Las Vegas, 1999.

[3]S.K. Rhee, H.S. Tsang, and V.S. Wang, Friction - Induced Noise and Vibration of Disc Brakes, *Wear, Vol. 133*, 1989, 39.

[4]H. Abendroth, Advanced/Progress in NVH Brake Test Technology, *Proceedings 16th Annual SAE Brake Colloquium and Engineering Display*, 1998, 21- 32.

[5]M. Nouby, J. Abdo, D. Mathivanan, and K. Srinivasan, Evaluation of Disc Brake Materials for Squeal Reduction, *Tribology Transactions, 54*:4,2011, 644-656.

[6]M. J. Trichés, N. Y. Samir, and R. Jordan, Reduction of squeal noise from disc brake systems using constrained layer damping, *J. of the Brazilian Society of Mechanical Science and Engineering, Vol. 26*, 2004, 340-348.

[7]Tzu Fu Chen, *Relationship between Formulation and Noise Of Phenolic Resin Matrix Friction Lining Tested In Acoustic Chamber on*

Automotive Brake Dynamometer, M.Sc. Thesis, Southern Illinois University, 2005.

[8]K. B. Dunlap, M. A. Riehle, and R. E. Longhouse, An investigative overview of automotive disc brake noise, *SAE Paper 1999-01-0142*.

[9]M. Nouby, and K. Srinivasan, Simulation of structural modifications of a disc brake system to reduce brake squeal, *Proc. IMechE, Part D: J. Automobile Engineering, Vol. 225*, No. 5, 2011, 653–672.

[10] M. Eriksson, *Friction and Contact Phenomena of Disc Brakes Related to Squeal,* PhD Thesis, UPPSALA, 2000.

[11] K. A. Cunefare, and A. J. Graf, Experimental active control of automotive disc brake rotor squeal using dither, *Journal of Sound and Vibration, Vol. 250*, No. 4, 2002, 575-590.

[12] S. James, An experimental study of disc brake squeal, PhD Thesis, University of Liverpool, 2003.

[13] V. Vadari, and M. Albright, An introduction to brake noise engineering, *j. sound and vibration, Vol 35-7*, 2001, Roush Industries Inc., Livonia, Michigan.

[14] M.A. Chowdhury, and M.M. Helali, The effect of frequency of vibration and humidity on the coefficient of friction, *Tribol Int,39*, 2006, 958-962.

[15] J. Abdo and E. Shamseldeen, Experimental technique for characterization of friction in dry contact, *Journal of solid mechanics and materials Engineering, 472*, 2008, 1197-1208.

[16] E.J. Berger, C.M. Krousgrill, and F .Sadeghi, Stability of sliding in a system excited by a rough surface. *ASME, 119*, 1997, 672-80.

[17] J. Todorovic, C. Duboka and Z. Arsenic, Modelling of friction materials tribological properties for the assessment of braking force distribution, *IMechE paper No. C382/057*, 1989.

[18] J. Abdo, and T. Mahmoud, The Effect of Frequency and Amplitude of Vibration on the Coefficient of Friction for Metals, *Wseas Transactions on Applied And Theoretical Mechanics, Volume 3,* Issue 7, 2008.

[19] S. Smyth, and H. J. Rice, Measurement of dry sliding friction rubbing noise using nearfield acoustic holography, *Acta Acust United Ac 95*, 2009, 247–258.

[20] M.N. A. Hamid and Z.M. Ripin, Analysis Of Brake Shoe Vibration Using Multi Body Dynamics Approach, *Seminar on Advances in Malaysian Noise Vibration and Comfort*, 17-18 May 2005.

[21] B L. aillet, S. D'Errico, and B. Laulagnet, Understanding of the squealing noise using the temporal finite element method, *Journal of Sound and Vibration, Vol. 292,* 2006, 443–460.

[22] O. Giannini, A. Akay, and F. Massi, Experimental analysis of brake squeal noise on a laboratory brake set-up, *Journal of Sound and Vibration, Vol. 292*, 2006, 1–20.

Biographies

Amr M. Rabia is an assistant lecturer in Automotive and Tractor Eng. Dept., Minia University, Egypt. He received his B.Sc. from Automotive and Tractor Eng. Dept., Minia University, Egypt in 2007. Presently, he is pursuing M.Sc. in Minia University. His areas of interests are finite element methods, noise and vibrations of vehicle.

Nouby M. Ghazaly is an assistant Professor in Automotive and Tractor Eng. Dept., Minia University, Egypt. He obtained his PhD from Anna University, Chennai, India in 2011. He has to his credit more than 22 research papers in the areas of vehicle dynamics, noise and vibrations, finite element methods and design of experiments. He is a Technical Committee Member and a Reviewer of several international journals and conferences. He is currently serving as a consulting engineer of ATALON for testing and consulting engineers, India.

Ali M. Abd-El-Tawwab is an Associate Professor and Head of Automotive and Tractor Eng. Dept., Minia University, Egypt. He has many international and notional journal and conference papers to his credit. he has around 26 years of experience in teaching and research in the areas of Vehicle Ride Comfort, Active Suspension System Design and Control, Noise and Vibration Control, Computer Programming, Vehicle Mathematical Modeling and Vehicle Performance.