THE EFFECT OF FULL ANNULAR RUB ON THE ROTATING MACHINERY SYSTEM CONSIDERING DIFFERENT RUB MATERIALS AND SHAFT RUNNING SPEEDS

Hamit SARUHAN[1], Suat SARIDEMİR[2], Ömer ERKAN[3]

In this study, the effect of full annular rub on the rotating machinery system considering different rub materials and shaft running speeds was experimentally studied. Experiments were carried out for the rub materials - copper, bronze, brass, soft plastic, hard plastic, steel 304, steel 316, and steel 2379. The force and vibration signatures of shaft rub on bearing housing were analyzed. The results showed that the vibration amplitude of inboard bearing housing close to the motor increased significantly with the shaft speed increased. The spectrum for the soft plastic rub material found to has a unique characteristic so that the vibration level was lower than the baseline (without rub material) vibration.

Keywords: Shaft rub, annular rub, vibration spectrum, force signature, bearing housing, rotating machinery

1. Introduction

The demanding requirements placed on modern rotating machinery system have introduced a need for higher speeds and lower vibration levels. Rotating machinery often have problems of instability when working at high rotating speed, which can result in sudden failures of the whole system or parts of it [1]. Accurately predicting the vibration characteristics of the rotating machinery system has become increasingly important. A typical rotating machinery system is composed of various components, such as shafts, disks, and support bearings. These massive and flexible components absorb and dissipate energy when subjected to disturbances, and produce a unique pattern of a variety of response [2]. There are a variety of rubs that can occur in the rotating machinery system with different rub locations such as seals, bearings, etc. and rub classifications such as full annular, partial, bouncing, etc. A rub may also occur in a variety of forms [3] due to excessive shaft vibration, mass unbalance or initial misalignments [4]. It can maintain itself, becomes more severe, and leads to higher vibration level [5]. So, the shaft rub is an undesired contact between rotating and stationary mechanical parts. As a result of the rub, the normal

[1] Assoc. Prof., Dept. of Mechanical Engineering, Düzce University, Turkey e-mail: hamitsaruhan.duzce.edu.tr
[2] Assist. Prof., Dept. of Manufacturing Engineering, Düzce University, Turkey
[3] PhD., Dept. of Manufacturing Engineering, Düzce University, Turkey

operation of the rotating machinery system is effected and generally worsened. Ignoring the occurrence of the rub may lead to catastrophic breakdown of the system. The rub introduces a reaction force at the rotor's periphery which influences the rotating system dynamics. Thus, the shaft rub in rotating system generates dynamic forces at shaft support bearings. So, shaft support bearings can provide a variety of information about the rub related force and vibration signatures. The rotor rubbing phenomenon has previously studied by researches [6-8] that have made great contributions on the rotating machinery system dynamics with rubbing. Muszynska [6] carried out a literature survey on full annular rub, made a comprehensive review, and gave a list of previous papers on the rub-related vibration phenomena during rub. Beatty [8] proposed a mathematical model for rubbing forces. Large amount of research work [9–12] has been recently done and great progresses have been made for the rub phenomena, whereas investigation of vibration characteristic of a rubbing system for the different rub materials has hardly been seen in the published literatures. Thus, the majority of works was focused on the development of some mathematical models in order to make the rubbing phenomena more accurately to be understood. The effect of different rub materials and speeds on vibration signatures are key issues in rotating machinery system [13], [14]. The rub should be considered in design by using proper materials. In the present study, serial tests are performed to compare vibration responses by looking at bearings housing vibration behavior using different rub materials and shaft speed conditions.

2. Experimental Setup

The experimental apparatus with a mechanical rub kit for understanding of the characteristics of the rub phenomenon is shown in Fig. 1. The apparatus consists of a shaft with length of 850 mm and diameter of 19.05 mm. The shaft is coupled with a flexible coupling to minimize the effect of the high frequency vibration generated by the 0.5 hp motor. A three-phase AC induction motor is connected to a variable speed control unit for achieving variable speeds. The motor can be run in the speed range of 0-3600 rpm. The shaft is supported by two identical ball bearings fitted into the support housings. The inboard bearing housing (close to motor) is consists of force transducers. Two disks of 151.8 mm in diameter, 15 mm in thickness, and 671.5 grams in weight are mounted along the shaft. The mechanical rub kit consists of an adjustable tool holder for the rub material, a vertical post, a horizontal bar and adjustable swivel clamping mechanism having anti-vibration lock. A spring inside the tool holder is compressed and exerts a moderate pushing force which presses the rub head against the shaft. Therefore, the rub head maintains continuous contact with the shaft. So, the full annular rub contact occurs over the entire vibration cycle, maintaining continuous contact as shown in Fig. 1, (see marked number 15).

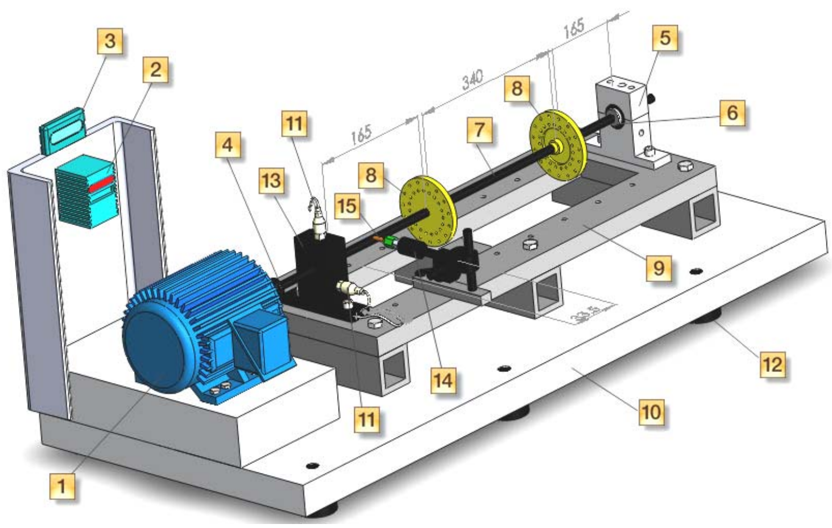

Fig. 1. Experimental test rig: (1) ½ HP Motor; (2) Variable speed controller; (3) Tachometer; (4) Flexible coupling; (5) Bearing housing; (6) Ball bearing; (7) Shaft; (8) Disk; (9) Extended rotor deck; (10) Base; (11) Accelerometer; (12) Rubber isolators, (13) Bearing housing with force transducers; (14) Mechanical rub kit; (15) Rub material

The force and vibration signatures of the inboard bearing housing in the vertical and horizontal directions are measured with force transducers and two accelerometers (608A11) having a sensitivity of 100 mV/g and frequency range up to 10 kHz. The accelerometers are mounted at 90^{o} on the bearing housing. The system is composed of DAQ (Data Acquisition) card provides four channels for vibratory response acquisition and one channel for rotational speed acquisition. DAQ channels were set as ch1 and ch2 for force transducer while ch3 and ch4 for inboard bearing housing to measure the vibration response in the vertical and horizontal directions respectively. All channels are simultaneous. PCI bus ensures high speed (102.4 K samples/sec.) for DAQ. The data were collected using the VibraQuest™ software and hardware system. The data collection system consists of a high bandwidth amplifier designed for the vibration signals. The data recorder is equipped with low-pass filters at the input stage for anti-aliasing. The resolution was 6400 spectra lines using Hanning window. The resolution indicates the number of lines used to plot the spectrum. To investigate the rub induced forces and their effect on the system vibrations, nine test cases were conducted. Each test case with the same combination of the experimental set-up was conducted for four different shaft speeds to observe behavioral changes of the system considering force and vibration signatures. Thus, the influence of rub materials with respect to shaft running speed on the shaft was the main consideration.

3. Results and Discussions

Because the shaft rub involves shaft interaction with mechanical rub, complex rotor dynamic behaviors that produce a wide variety of vibration symptoms are observed. Full annular rub was simulated with eight types of the rub materials, namely soft plastic, copper, bronze, brass, hard plastic, steel 304, steel 316, and steel 2379 (The Society of Automotive Engineers (SAE) designated steel grade). Experiments were carried out for four shaft speeds 500, 1000, 1500, and 2000 rpm. Fig. 2 gives the first and second maximum peaks of vibration spectrum from ch3 and ch4 for all test cases with respect to shaft speeds. Comparing the first and second maximum peaks of inboard bearing housing in the vertical direction (ch 4) to maximum peaks in the horizontal direction (ch 4), the vibration of without rub head (baseline) and rub one have almost the same level of amplitude in the vertical direction and the level increases with increase in the shaft speed. From ch 3, it can be seen that the spectrum with higher shaft speed for the hard rub materials has significant difference to that the soft rub materials and baseline. The spectrum for the soft plastic rub material has a unique characteristic so that the vibration level is lower than the baseline vibration. It can be concluded that the soft materials attempt to balance structural excitation of baseline when comparing with the hard materials used. It can be seen in Fig. 2, low vibration amplitudes were obtained for low running speed while higher were obtained for higher running speed.

The amplitude spectrum of inboard bearing housing with and without the rub for 2000 rpm is illustrated in Fig. 3(a), (b), and (c). The vibration signatures used for displaying and analyzing were collected from the inboard bearing housing in the vertical direction. It can be observed in Fig. 3(a), (b), and (c) that the rub generates many structure resonances. Under a certain running speed, the excited structure resonance positions around 1250 Hz and 2500 Hz do not change, but the values of vibration spectrum change with type of rub materials. Thus, the more severe the rub generates the higher and the more resonance components. The vibration spectra for the copper, bronze, and brass materials are close to each other. Also, it is noted that the resonance are not much appearing at higher frequencies.

The harmonics of force signature at inboard bearing housing in the horizontal direction (ch2) for the shaft speed for of 2000 rpm are shown in Fig. 4(a), (b), and (c). The parallel dotted lines indicate the locations of shaft speed of 2000 rpm with multiply by 1.5 and its harmonics. The harmonics of force signature are to be quite distinct for all test cases. Force signature values for the hard plastic and steel 2379 rub materials are found to be higher than the others materials.

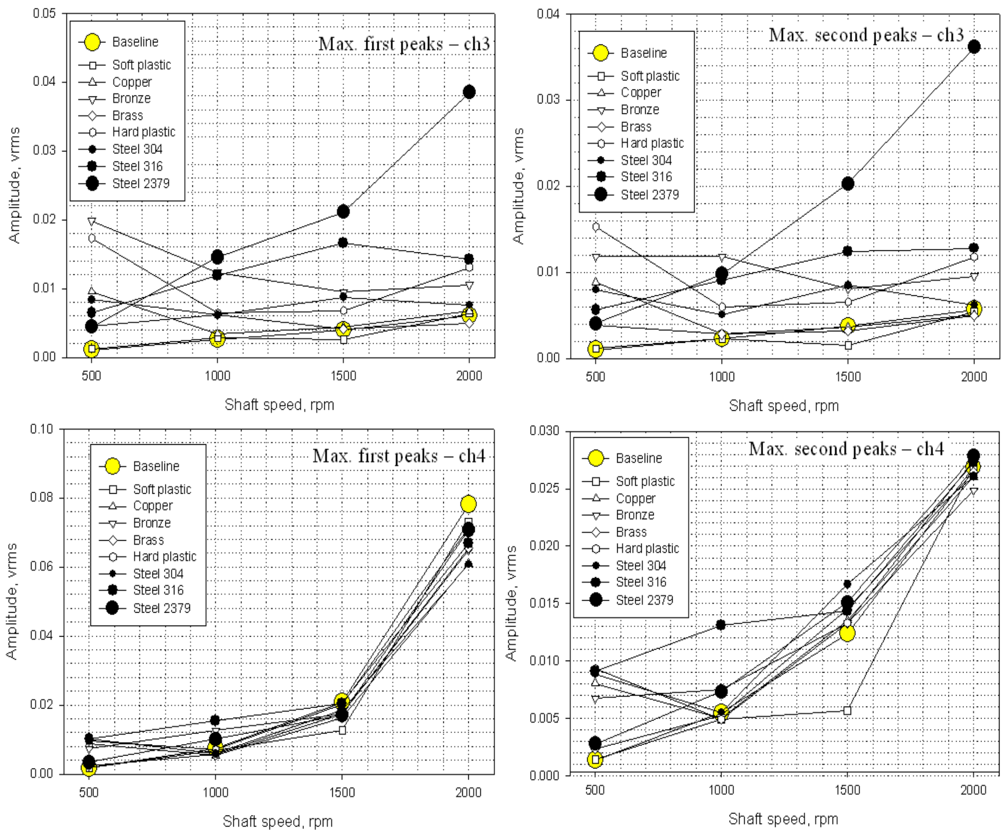

Fig. 2. The first and second maximum peaks of vibration spectrum for ch3 and ch4

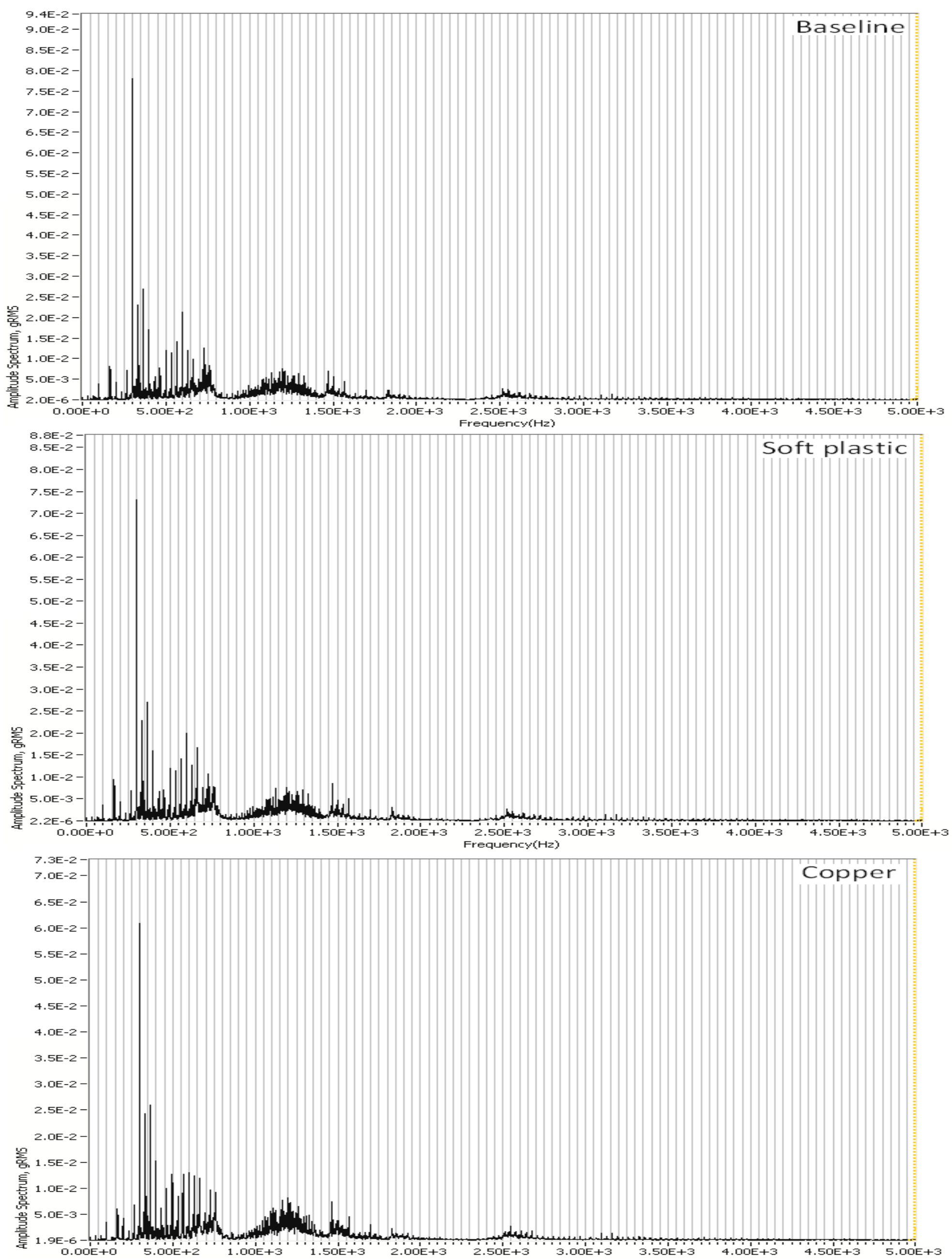

Fig. 3(a). Amplitude spectrum (0 ~5 kHz) at inboard bearing housing with and without rub head (baseline) for the shaft speed of 2000 rpm

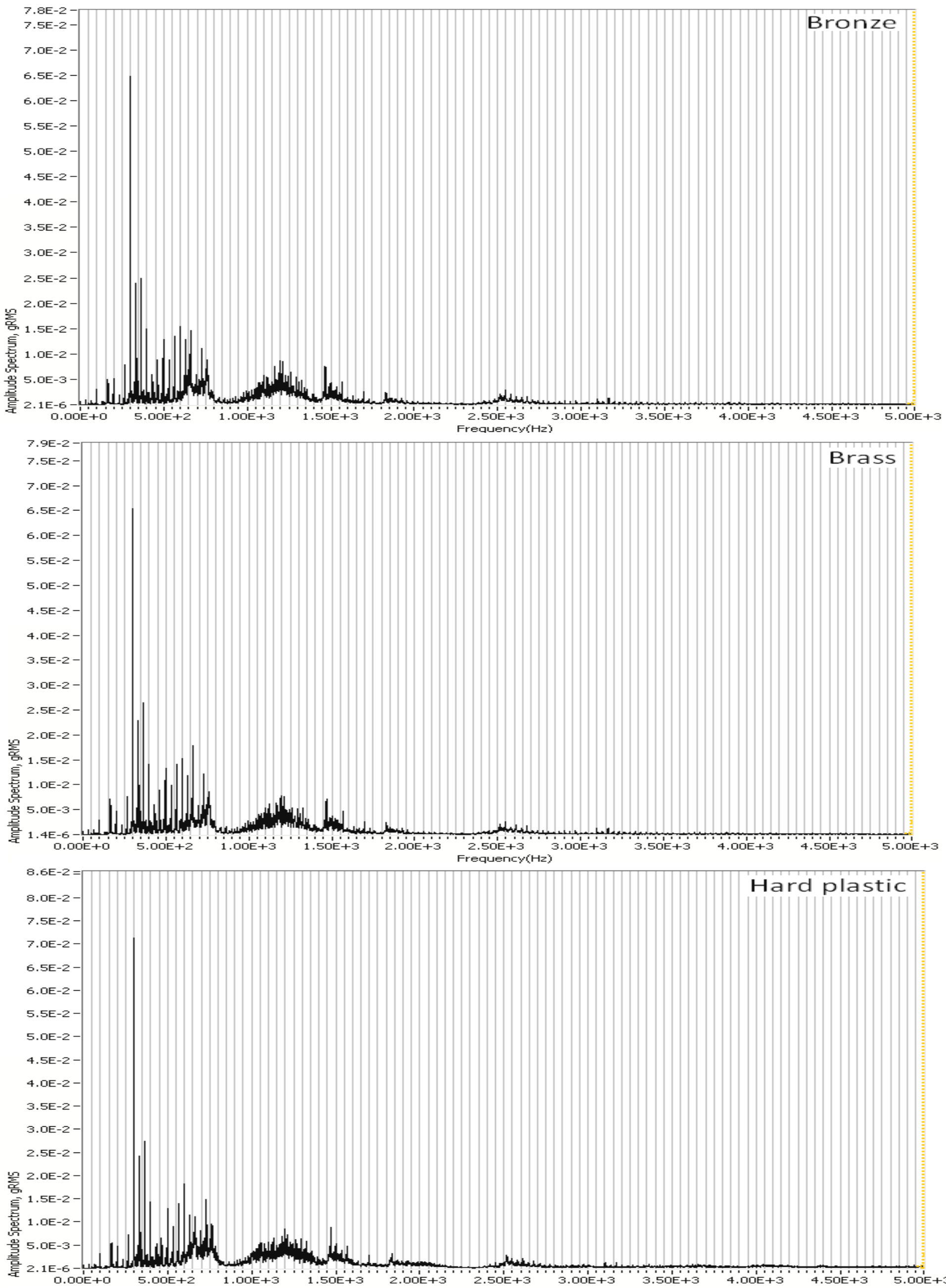

Fig. 3(b). Amplitude spectrum (0 ~5 kHz) at inboard bearing housing with and without rub head (baseline) for the shaft speed of 2000 rpm

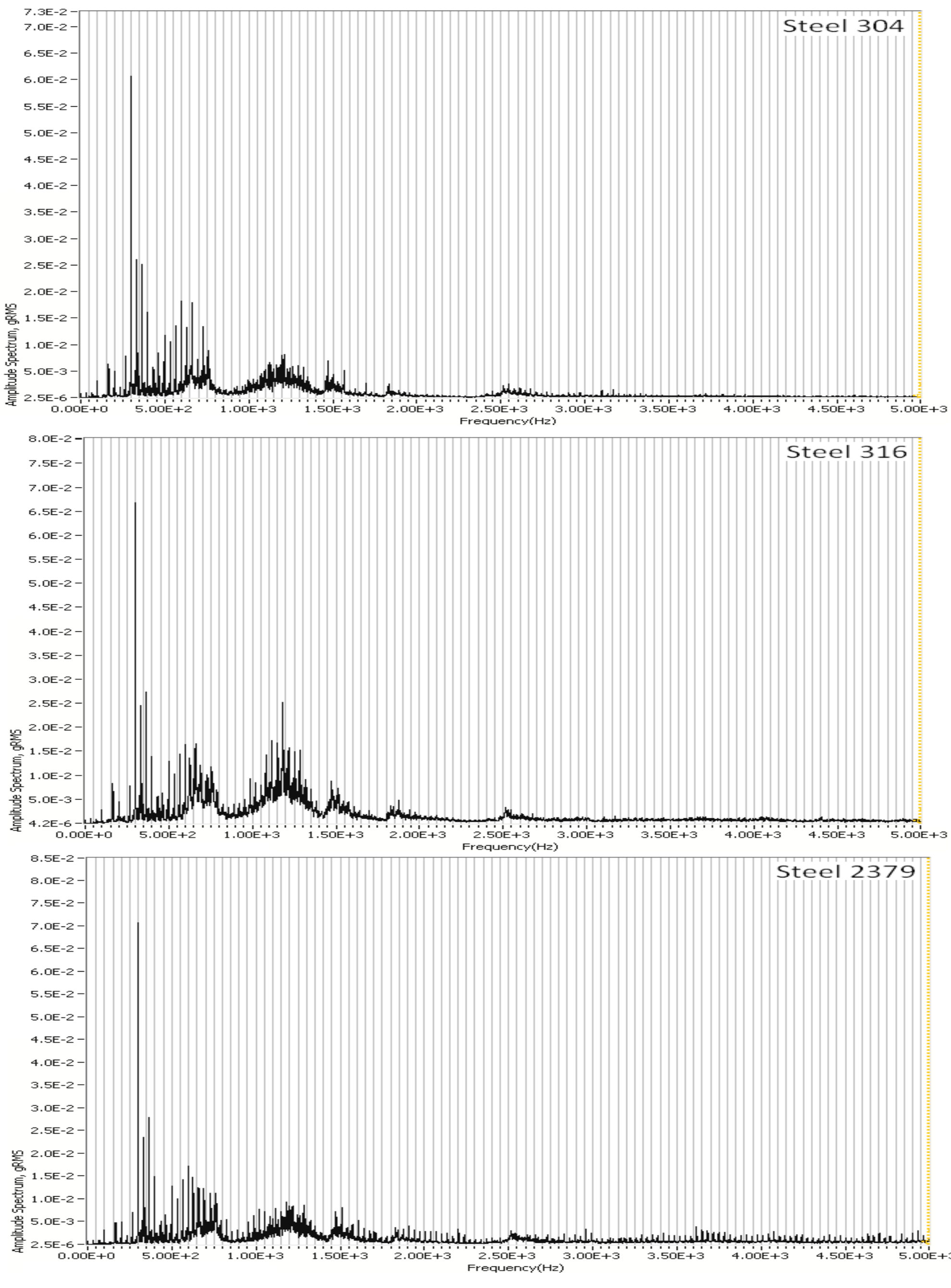

Fig. 3(c). Amplitude spectrum (0 ~5 kHz) at inboard bearing housing with and without rub head (baseline) for the shaft speed of 2000 rpm

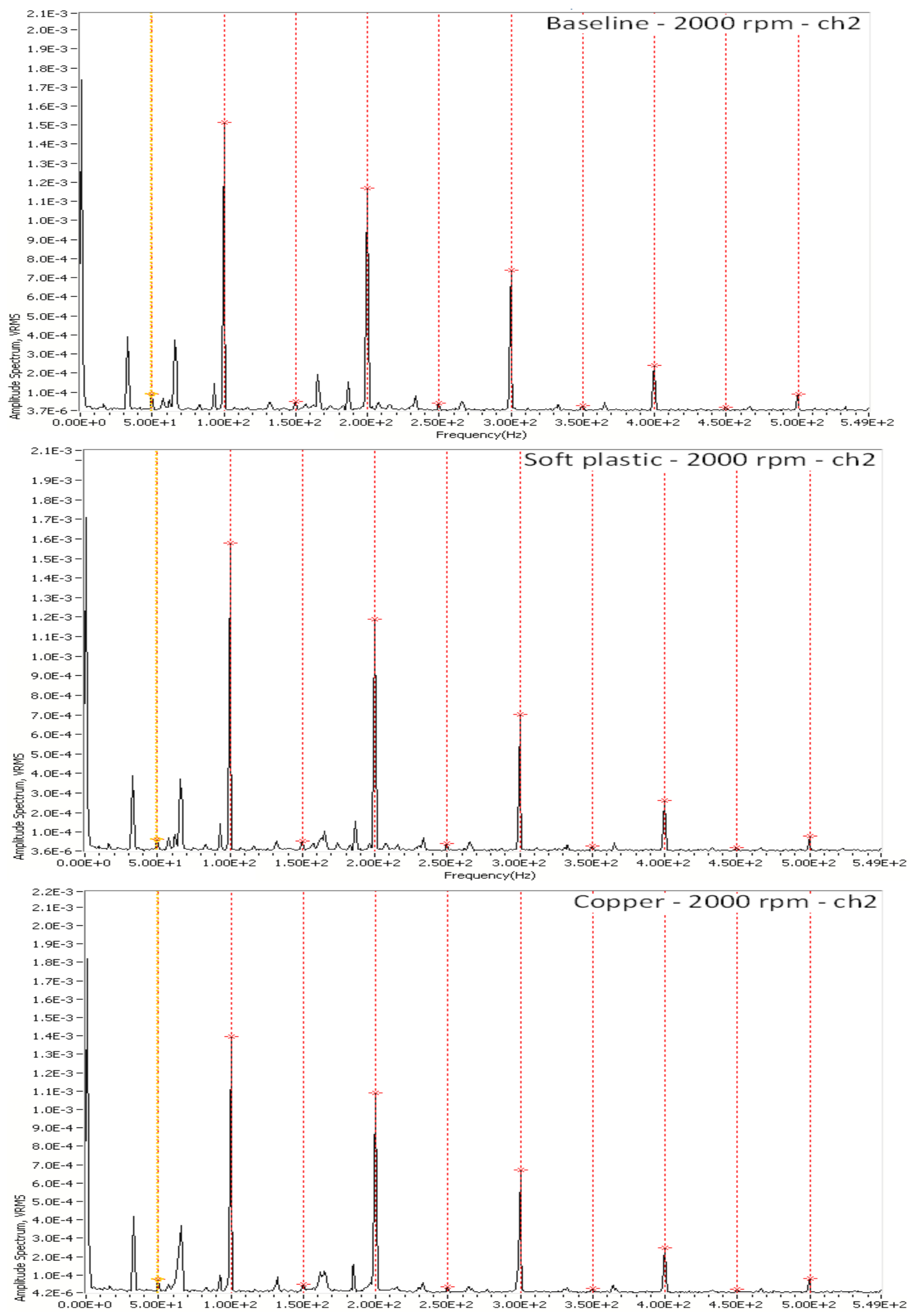

Fig. 4(a). The harmonic frequencies at inboard bearing housing in the horizontal direction (ch2) for shaft speed of 2000 rpm with multiples by 1.5

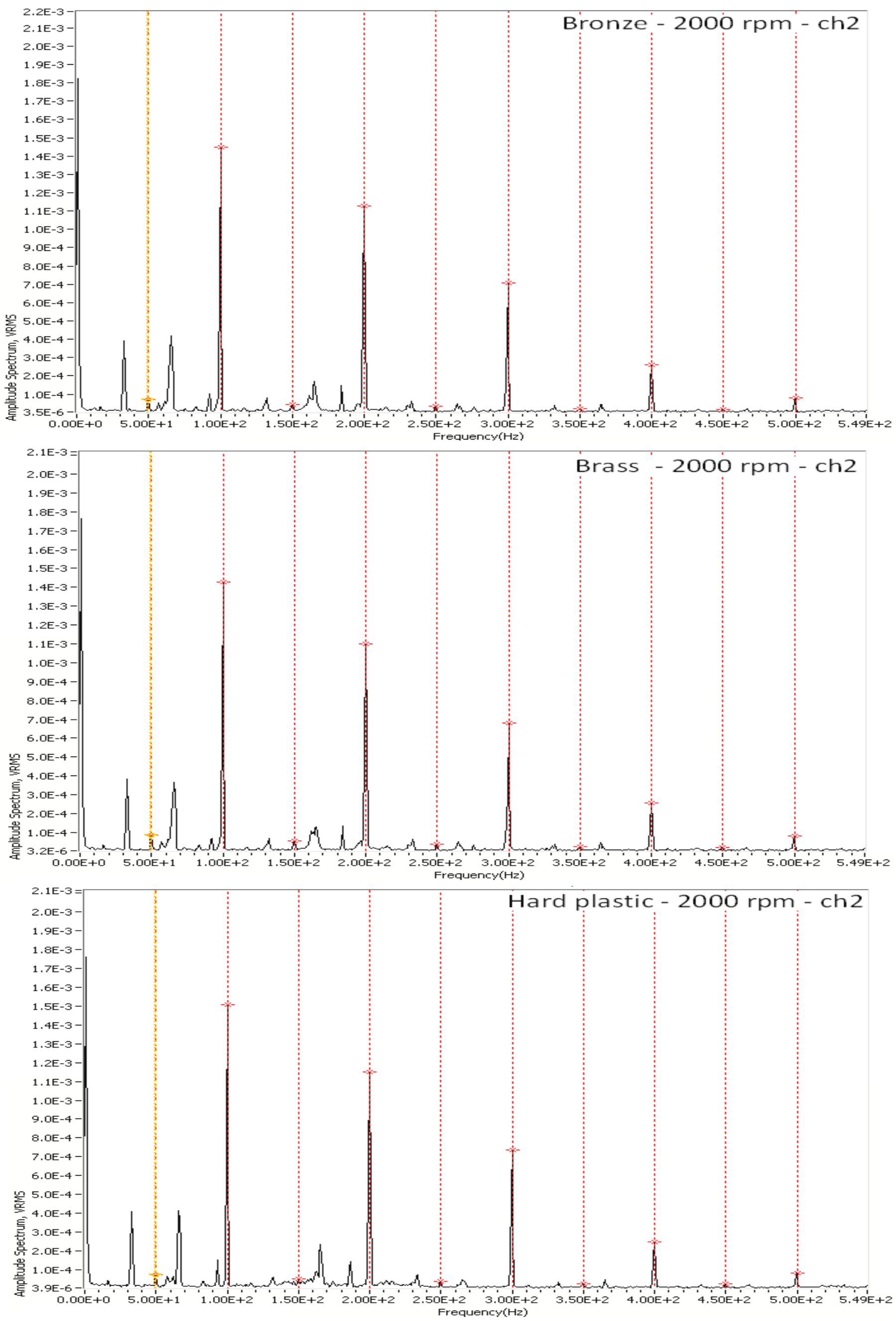

Fig. 4(b). The harmonic frequencies at inboard bearing housing in the horizontal direction (ch2) for shaft speed of 2000 rpm with multiples by 1.5

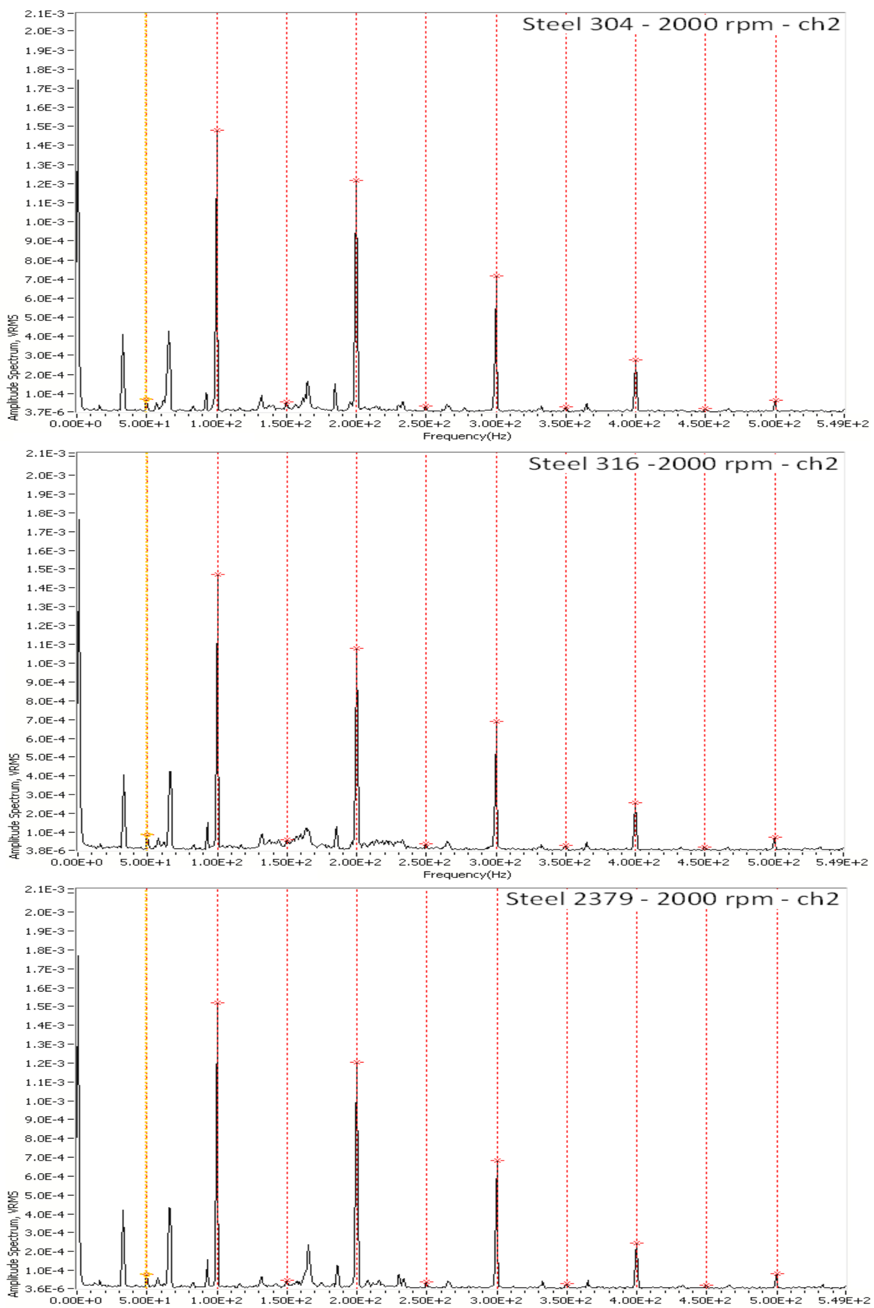

Fig. 4(c). The harmonic frequencies at inboard bearing housing in the horizontal direction (ch2) for shaft speed of 2000 rpm with multiples by 1.5

4. Conclusions

Identifying and analyzing force and vibration signatures caused by the rub at bearing housing are very important in preventing the rub related rotating machinery system failure. To investigate the rub induced forces and their effect on the rotating machinery system vibration, nine sets of experiments were conducted. The mechanical rub kit is used that can simulate the condition of the full annular rub. The rub materials with respect to four different shaft speeds are tested as a control parameter to observe the vibration responses and used to see the influence of different hardness and friction on the rotating machinery system vibration. Several observations of the rub effects on bearing housing vibration are presented. In general, the vibration amplitude at inboard bearing housing increases significantly with the shaft speed increase. It is observed that the vibration spectrum for the soft plastic rub material has a unique characteristic so that the vibration level is lower than the baseline (without rub head) vibration. Also, it can be concluded that the soft materials attempt to balance structural excitation of the baseline when comparing with the hard materials used. The harmonics of force signature are to be quite distinct for all test cases. Force signature values for the hard plastic and steel 2379 rub materials are found to be higher than the other materials. It can be concluded that the rub in fact should be a design consideration by use of proper materials. Further research will be focused on identification of vibration signature caused by rub on bearing housing for preventing rub related rotating machinery failure using both experimental and theoretical study having considering rub material and conditions of usage.

R E F E R E N C E S

[1]. *Bavastri, C.A., Ferreira, E.M.S., Espíndola, J.J., and Lopes, E.M.* Modeling of Dynamic Rotors with Flexible Bearings due to the use of Viscoelastic Materials, Journal of the Brazilian Society of Mechanical Sciences and Engineering, 30 (1), pg. 22-29, 2008.

[2]. *Arora, R.K.* Axisymmetric finite elements for rotor dynamics, Master Thesis, University of Kentucky, Lexington, 1987.

[3]. *Ahmad, S. and Ghauri, M.K.K.* Dynamic behavior of rotor surrounded by outer casting with small annular clearance, Technical Journal, University of Engineering and Technology Taxila, pg. 42-57, 2011.

[4]. *Ziaei-Rad, S., Kouchaki, E., Imregun, M.* Thermoelastic modeling of rotor response with shaft rub. Journal of Applied Mechanics, 77, 2010.

[5]. *Choi, Y.S.* On the contact of partial rotor rub with experimental observations, Korean Society of Mechanical Engineers (KSME) International Journal, 15 (12), pg.1630-1638, 2001

[6]. *Muszynska, A.* Rotor to stationary element rub-related vibration phenomena in rotating machinery – literature survey, Shock Vibration Diagnostics, 2, pg.3-11, 1989.

[7]. *Child, D.W.* Rubbing induced parametric excitation in rotors, ASME J. Mechanical Design, 101 (4), pg. 640-644, 1979.

[8]. *Beatty, R.F.* Differentiating rotor response due to radial rubbing, Journal of Vibration, Acoustics, Stress, and Reliability in Design, 107, pg.151–160, 1985

[9]. *Lu, W., and Chu F.L.* Rub fault diagnostics by dynamic characteristics analysis of multi-disk rotor system, Damage Assessment of Structures, Key Engineering Materials, 204 (2) pg. 163–172, 2001.

[10]. *Gao, J.J. and Jiang, Z.N.* Research on fault mechanism of rotor to stator rub nonlinear vibration in high-speed turbo machinery, Damage Assessment of Structures, Proceedings of Key Engineering Materials 245 (2), pg.241–247, 2003.

[11]. *Chu, F.L., and Lu, W.* Experimental observation of nonlinear vibrations in a rub-impact rotor system, Journal of Sound and Vibration, 283, pg. 641-643, 2005.

[12]. *Chang-Jian, C. and Chen, C.* Couple stress fluid improve rub-impact rotor-bearing system – Nonlinear dynamic analysis, Applied Mathematical Modelling, 34, pg. 1763–1778, 2010.

[13]. *Hariharan, V, Srinivasan, P.S.S.* Experimental investigations on bearing housing vibration signatures caused by shaft rub. Strojnicky Casopis (Journal of Mechanical Engineering). 60, pg. 61-73, 2009.

[14]. The Effects of shaft rub on bearing housing vibration signature, Technical Report, SpectraQuest, 2006.