

# SOFTBALL BAT VIBRATIONS DURING THE SWING AND IMPACT: A PRELIMINARY ANALYSIS OF EMPIRICAL DATA

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The purpose of this study was to investigate softball bat vibrations during the swing and impact and to correlate the vibrations with characteristics of hitters and the swing. Four recreation-league college males and four females aged 21-23 yrs hit 15-25 pitched softballs with a high-performance aluminium softball bat (34 in, 28 oz). Analysis of strain gauge and videotaped records of 112 trials indicate that: 1. The frequency of bat oscillations during the swing ranged from 4.1 to 7.5 Hz, significantly below the 13 Hz of the lowest vibration mode of the clamped boundary condition; and 2. All hitters consistently demonstrated the effective utilisation of the diving board mode of vibration in timing the impact and swing such that the bat was 'releasing' elastic energy at impact that was stored during the swing.

KEY WORDS: baseball bats, equipment, striking implements.

**INTRODUCTION:** Baseball and softball manufacturers are now producing 'high performance' bats that purportedly provide a 'springboard' effect achieved by increasing the bat's flexibility. The rationale for this springboard effect assumes that longitudinal vibrations are excited during the swing and that the timing of the impact with the ball is such that the barrel of the bat is oscillating forward during impact. Several theoretical (Brody, 1986; Brody, 1990; Cross, 1998; Van Zandt, 1992) and empirical studies (Noble and Walker, 1993; Noble and Walker, 1994a; Noble and Walker, 1994b) have examined bat vibrations and performance during impact. However, none of these studies involved athletes swinging the bat at pitched balls. The findings and recommendations from these theoretical and laboratory-based studies may not be fully applicable to actual playing conditions. Furthermore, no studies have been found examining the undulations, or vibrations, of the bat while the bat is being swung at pitched balls. In a recent review article, Noble (1997) noted that, if it is assumed that a bat can be represented by a uniform rod rigidly suspended at the point of contact with the hands, then the various normal vibrational modes are only those for a rigid clamped rod. The lowest frequency mode, commonly called the diving board mode, corresponds to a vibration where the axis is at a nodal point and the barrel end is at a maximum. If the claims of bat manufacturers were true, then this 'diving board' mode would provide the 'springboard' effect. Presumably, this is accomplished by exciting the diving board mode during the swing in such a way that the barrel of the bat would be "releasing", or bending forward toward the incoming ball at impact. If the theoretical studies regarding the diving board mode of the bat are applicable during the swing of the bat, then the bat would begin oscillating at approximately 25 Hz during the early portion of the swing as the hitter applies torque-producing forces to the bat handle. This scenario would require the unbending of the bat to occur approximately 1/4 of the period of oscillation (40 ms) prior to contact, or 10 ms. While this characteristic of the skilled golf swing has been empirically verified (Cochran and Stobbs, 1986), no empirical data in support of this hypothesis applied to softball or baseball bats have been found.

The purpose of this study was to investigate softball bat vibrations during the swing and impact with pitched balls and to correlate these vibrations with selected characteristics of the hitters and swing.

**METHOD:** Four college males and four college females aged 21-23 years and with varying skill levels volunteered to participate in the study. All subjects regularly participated in organized recreational-league softball; however, their skill level ranged from moderate to exceptional. The range of subject mass was 75-110 kg and 47-65 kg for males and females, respectively. Each subject hit 15-25 pitched softballs with a high-performance aluminium softball bat (34 in, 28 oz). Three of the subjects 'choked up' on the bat (gripped the bat 2 or more cm from the knob end) while five used a knob end grip. Bat vibrations were obtained using two foil strain gauges bonded to the tapered region on the leading and lagging

surfaces of the bat and interfacing the output to a computer. Wires from the strain gauge were routed underneath the handle wrapping, emerged from the knob end of the bat and were threaded underneath the knit shirt of the hitter. These wires were connected to the AD board of a microcomputer and the output signal ( $\pm 10V$  DC) was sampled at 5000 Hz. Strain gauge output was proportional to the bending of the bat in only one plane (40 mv/microstrain), and was used to determine the lowest vibration mode under free-free and clamped boundary conditions in the lab as well as during the swings and impacts of the field tests. Because orientation of the bat during the swing was critical if the output was to provide an accurate representation of the bending of the bat during the swing, a strip of white tape was placed on the barrel end of the bat so that bat orientation could be visually determined. Subjects were told to bat so that this tape was vertically oriented during the latter part of the swing prior to impact. A SVHS 60-Hz video camera was placed near first base for right-handed hitters and near third base for left-handed hitters. From this view, the initiation of the swing and impact and the orientation of the bat could be clearly viewed. Post-impact ball velocity was measured with a radar gun with a resolution of .23 m/s. Subject rating of the quality of the swing and impact (1=**worst**, 10=**best**) and a description of the outcome of each hit were obtained for each trial. Only trials wherein the rating was 4 or above and acceptable recordings were obtained were selected for detailed analysis. A total of 112 trials were selected for examination. Comparisons among subjects of selected waveform characteristics were made using ANOVA procedures.

**RESULTS AND DISCUSSION:** The lowest mode of vibration under clamped boundary conditions (e.g., the diving board mode) was 13.3 Hz while the lowest mode under free-free (loosely held) conditions was 156 Hz. Figure 1 provides a characteristic waveform of the best hitter in the study. The swing rating was 9 and the post-impact ball velocity was 38 m/s.

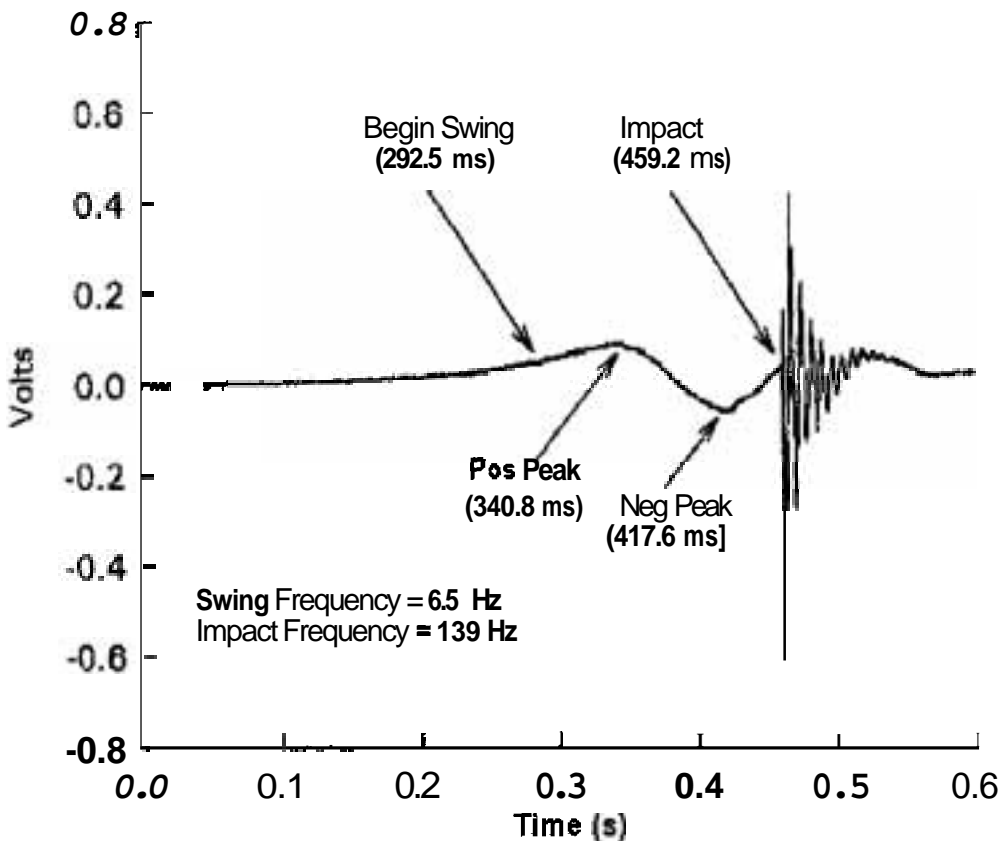


Figure 1 - Characteristic waveform of good hitter during a good swing and hit.

During the stance of this hitter, the bat was held in a nearly vertical orientation. A positive output indicates that the bat is bending toward the leading edge of the bat. The bat does not

reach a horizontal orientation until after the positive peak, then begins to bend backward, away from the oncoming ball, reaching a negative peak at approximately 36 ms prior to contact (PC). The bat is then in the process of straightening (bending forward) at impact, and continues to straighten after impact. The most significant variation of this characteristic curve across subjects was the absence of the first positive peak in subjects who held the bat in a near-horizontal position during the stance. In every trial selected for examination, the bat bent backward during the swing, and was restoring, or bending forward at impact. These observations support the claims of bat manufacturers that the diving board vibration mode is exhibited during the swing of softball hitters. The frequency of the bat undulations during the swing (SWFREQ) and the lowest mode of vibration at impact (IMPFREQ) were obtained by direct measurement of the time between waveform peaks. SWFREQ was calculated from  $1/2T$ , where T was the elapsed time between the positive and negative peaks during the swing. In waveforms lacking a positive peak, the instant the waveform began decreasing was used as the onset of the swing waveform. Table 1 shows subject means and ANOVA results for SWFREQ and IMPFREQ.

**Table 1 Comparison of Subject Means for SWFREQ, and IMPFREQ.**

SWFREQ (Hz) <sup>1</sup>				IMPFREQ (Hz) <sup>2</sup>			
Subj <sup>3</sup>	N	Mean±STDerr	Comp <sup>4</sup>	Subj <sup>3</sup>	N	Mean±STDerr	Comp <sup>4</sup>
5F	10	7.5±0.32	A	3F	15	154.5±1.33	A
9F	18	6.7±0.26	A B	9F	18	154.4±1.08	A
2M	13	6.2±0.20	B C	5F	10	153.0±1.15	A
4M	12	5.4±0.16	C D	6F	12	146.1±0.77	A B
7M	14	4.8±0.77	E D	4M	10	141.4±2.44	B C
8M	18	4.7±0.10	E D	7M	11	141.4±2.86	C
3F	15	4.2±0.16	E	2M	12	140.1±1.33	C
6F	11	4.1±0.50	E	8M	14	138.8±1.50	C
Mean	111	5.4±0.16		Mean	102	146.8±0.85	C

<sup>1</sup>ANOVA found subject means significantly different (F-ratio=10.98, df=7, p<.0001).

<sup>2</sup>ANOVA found subject means significantly different (F-ratio=10.23, df=7, p<.0001).

<sup>3</sup>'M' indicates male, 'F' female. <sup>4</sup>Means with the same letter are not significantly different.

Observation of the waveform and the results of the SWFREQ data indicate clearly that the bat was not oscillating during the swing at the expected 13 Hz frequency of the clamped boundary condition. Furthermore, there were significant differences among subjects with mean subject values ranging from 4.1 to 7.5 Hz. While this value might be expected to be related to the swing time (time from beginning of bat movement forward until impact), no significant correlations were found between these variables. The highest SWFREQ values were found for subjects 5 and 9. Both were females and both choked up on the bat. The lowest SWFREQ values were noted for subjects 3 and 6. Both of these subjects were also female. No Subject or waveform characteristics were identified to account for either within-subject or between-subject variability in SWFREQ. A significant relationship between swing time and SWFREQ was expected; however, none was found. Two factors may have contributed to the lack of significance between these two variables: 1. Strain gauge output was dependent on the orientation of the bat, which was noted to vary somewhat both within and between subjects; and 2. Swing time was determined from video records, which are subject to low resolution (60 Hz) and subjective determination of beginning and end points.

The mean IMPFREQ frequency for all subjects (147 Hz) was significantly below the 156 Hz frequency of the free-free boundary condition. Also, there were significant differences among the subjects with mean subject values ranging from 138.8 to 154.5 Hz. ANOVA of subject means showed that the IMPFREQ for females was significantly higher than that for males and that the 3 subjects who had the highest scores choked up on the bat two or more cm from the knob end. A possible reason for this gender difference is because of the greater mass of the hands and forearms, and possibly firmer grip, of the male subjects, which might tend to add a greater effective mass to the knob end of the bat. The proximal node of the fundamental vibrational mode of softball bats has been shown to be more than 15 cm from the knob end of the bat (Noble and Walker, 1993). Thus, the addition of mass at the knob end would be expected to lower the frequency of this mode while the removal of mass at the knob end by choking up on the bat would be expected to increase the frequency.

The magnitude of bat bending during the swing and the degree of bending of the bat at impact were analysed in order to further examine the hypothesis that the hitter utilises the diving board mode to more effectively impart momentum to the ball at impact. This analysis indicated that, while there were significant differences in the extent of bat bending at impact among subjects, on average, impact occurred when the bat was more than 21% straightened from the maximum bending position. Subjects were quite consistent in producing swings resulting in either negative or positive bending values at impact; however, no subject or waveform characteristics were identified that correlated with this variable. The magnitude of bat bending was significantly related to post-impact ball velocity for all subjects ( $r=.56$ ,  $p<.0001$ ). This relationship may have been stronger if the sensitivity of the strain gages to bending were not dependent on bat orientation during the swing.

**CONCLUSIONS:** The following conclusions are supported by the findings of this study: 1. Vibrations of softball bats during the swing do not approximate that of the clamped boundary condition, but appear to be related to the torques produced by the hitter's hands during the swing; 2. The lowest mode of vibration produced by the impact of the ball with the bat is similar to, but significantly below the mode of vibration of the free-free boundary condition; and 3. Bat manufacturers' claims that baseball and softball bats with greater longitudinal flexibility provide a 'springboard' effect at impact through the release of elastic energy stored during the swing is supported by the findings from this study. Recreation-league softball players of widely varying skill levels have demonstrated the ability to repeatedly produce swings resulting in impacts when the bat is straightening from the bent position developed during the swing. Increasing the flexibility of baseball and softball bats beyond those now being produced may improve the effectiveness of the bat in imparting velocity to the ball.

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