Development of a Vibrator Used for Accelerating Orthodontic Treatment

Xiangyu Zhi[1,2#], Zaijin Li[1,2#], Zeyang Xia[1*], Qunfei Zhao[3*], Gang Yu[2]
1.Shenzhen Institutes of Advanced Technology, Chinese Academy of Sciences, and
The Chinese University of Hong Kong, Shenzhen, China
2.Harbin Institute of Technology (HIT) Shenzhen Graduate School, Shenzhen, China
3.Department of Automation, Shanghai Jiao Tong University, and Key Laboratory of
System Control and Information Processing, Ministry of Education of China, Shanghai, China
# These authors contributed equally to this work
∗ Correspondence should be addressed to Profs. Xia and Zhao at
zy.xia@siat.ac.cn/zhaoqf@sjtu.edu.cn/+86-755-8639-2181

***Abstract*— Studies have shown that applying a vibration of certain frequencies and intensities on the tooth can accelerate tooth movement, thus shorten orthodontic treatment duration. The optimal frequency may be related to the natural frequency of the tooth-periodontal ligament(PDL)-bone complex (TPBC), therefore we designed a vibrating device which can measure the natural frequency of the TPBC, and produce vibration load with customized frequencies and intensities. This device consists of four parts, vibration source, vibration frequency modulator, vibration amplitude modulator, natural frequency measurement module. To optimize the vibrator's design, specifically structure and natural frequency, static analysis and modal analysis were both made. The application method of the vibrator is also introduced. The designed vibrator can customize vibration load and obtain the natural frequency of TPBC, and it will be used for experiments to obtain the relation between the optimal frequency and the natural frequency of TPBC.**

***Index Terms*— vibration; orthodontics; natural frequency.**

I. INTRODUCTION

Orthodontic treatment may result in solid tooth loss, root resorption, and other side effects. Studies have shown that these side effects are relate to treatment time, so acceleration of orthodontic tooth movement thus shortening the treatment period is an effective solution[1]. In recent years, using vibration load for accelerating orthodontic tooth movement has drawn the attention of many researchers. Experiments on animals have shown that applying a vibration of certain frequencies and intensities on the tooth not only accelerates tooth movement, but also make the orthodontic results more stable [2-3]. Currently the optimal frequency and intensity of the vibration load are not known, however it is believed that they are related to physical properties of the tooth-periodontal ligament (PDL)-bone complex (TPBC) on which the vibration load is applied. The natural frequency of the tooth in a specified direction is its inherent characteristics, and it is decided by TPBC. So the optimal frequency may be related to the natural frequency of TPBC. A device is needed for measuring the natural frequency of TPBC. Besides, another device which can produce vibration of certain frequencies and intensities is also needed [4-13].

Osstell, uses a small transducer and resonance frequency analysis to estimate the stability of a dental implant. Implant stability is measured by using the instrument together with the wireless SmartPeg attached to an implant or abutment. Because the mass of the SmartPeg makes a difference to the resonance frequency of the implant, the result is not accurate.

Implomates is another device for stability testing of dental implant. This device uses electromagnetic force to drive the impact head, then forces it to strike against the implant. During this process, the resultant vibration is detected via a piezoelectric microphone. Specific resonance frequency of the tested implant is determined from the relatively highest point with a peak amplitude value for vibration. To use this instrument, a spectrum analyzer is needed, which makes it complicated and inconvenient.

AcceleDent is a device which applies vibration load to teeth to accelerate orthodontic teeth movement. The device sends vibrations through the mouthpiece to the teeth and gums. But the vibration load of AcceleDent is applied to all teeth and cannot be applied to a specified tooth that we want.

In order to compensate for the lack of existing instrument, a new vibrator used for accelerating orthodontic treatment is developed. The device can test the natural frequency of TPBC as well as produce vibration of certain frequencies and intensities.

II. SYSTEM DESIGN

This vibrator consists of four parts, vibration source, vibration frequency modulator, vibration amplitude modula-

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tor, natural frequency measurement module. Different from AcceleDent, the vibration load of this vibrator has a certain vibrating direction. The frequency and amplitude of the vibration can be adjusted independently. This device can also apply vibration load to a specified tooth in a specified direction. Besides, the vibrator can test the natural frequency of TPBC. Fig.1 shows the system structure of the vibrator. Fig.1 (left) is the measuring mode and Fig.1 (right) is the vibrating mode.

Fig. 1. The system structure of the vibrator.

A. Vibration Source

Fig.2 shows how the vibration in a certain direction is generated. The motor shaft and the eccentric pin is linked by the eccentric block. There is a certain eccentric distance between the axis of the eccentric pin and the axis of the motor shaft, so when the motor runs, eccentric pin will drive vibrating rod to vibrate. To constraint the vibrating direction, vibrating rod is placed into a guide rail which is not drew in Fig.2. The motion curve of the vibrating rod is sinusoid. The vibrating frequency is equal to the frequency of the motor.

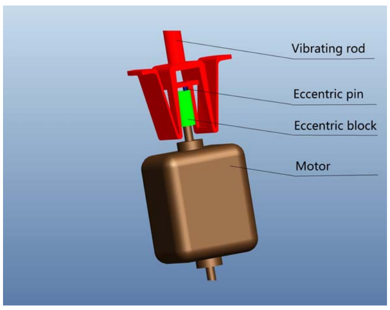

Fig. 2. Vibration source.

B. Vibration Frequency Modulator

In the part of vibration source, it is shown that the vibrating frequency is equal to the frequency of the motor, so changing the motor speed can change the vibrating frequency.The vibration frequency modulator consists of two parts, obtain the motor speed and control the motor speed.

There are two methods to detect the motor speed. One is using the photoelectric sensor based on photoelectric effect. The other method is using Hall sensor based on Hall Effect. Due to the limit of vibrator size, a small motor is chosen. Installing a magnet on the motor shaft is not convenient, so the first method is used to detect motor speed.

Pulse width modulation (PWM) output by a micro control unit (MCU) is used to control the motor speed. The greater the duty ratio of PWM, the faster the motor speed is.

C. Vibration Amplitude Modulator

The vibrating rod is sheathed with a sliding support block, as shown in Fig.3. The block serves as the pivot of reciprocating vibration. The right part of Fig.3 is the simplification of the principle of vibration amplitude modulator. The direction of the arrow indicates the direction of vibration. Changing the location of the sliding support block can change output amplitude of the vibration rod. There are two positions shown in Fig.3, position one and position two. The two positions correspond to different amplitudes at the same vibrating frequency. The amplitude at position two is bigger than that at position one. The sliding support block is connected to a screw. When rotating screw, the sliding support block will move up and down, then the vibrating amplitude is changed. The vibration amplitude modulator and the vibration frequency modulator are independent each other, so the vibrating frequency and amplitude can be modulated independently. This is an advantage which other orthodontic instruments do not have.

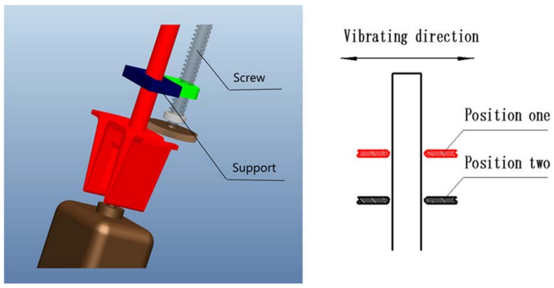

Fig. 3. Vibration amplitude modulator.

D. Natural Frequency Measurement Module

When structures of different materials, shapes and sizes are hit, the frequencies of the sound are not identical. The fact that different sound has different frequencies reflects the differences in the inherent characteristics of the structure.

When a subject is vibrated under dynamic load excitation, vibration of the structure surface will spread the sound to surroundings through the fluid medium. The frequency of the sound is related to the natural frequency of the subject. Studies have shown that the two frequencies are equal. The designed vibrator uses this principle to test the natural frequency of TPBC.

Fig.4 shows the designed structure for signal acquisition.

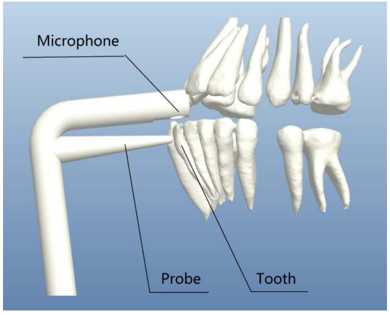

Fig. 4. Signal acquisition.

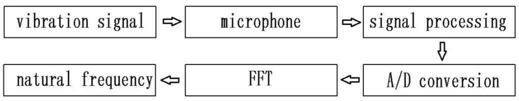

Fig. 5. Natural frequency acquisition.

The microphone is positioned 1cm above the striking tooth to collect the vibrational signal. Fig.5 shows the process of how to get the natural frequency of TPBC from the collected vibration signal. For there are many noises in the environment, signal filtering is needed after collecting the sound signal. Then A/D converter converts analog signals into digital signals for Fast Fourier Transform (FFT). FFT is used to convert the vibration signal from a time-domain to a frequency-domain format. The natural frequency of the test tooth is assessed through the tooth's peak mobility amplitude as reflected by the frequency response spectrum.

III. ANALYSIS OF MECHANICAL STRUCTURE

The designed device will provide a cyclic loading to vibrate the tooth. During using the device, the vibration frequency and amplitude may change several times. The device may fail if the vibration frequency coincides with one of the modal frequencies. And stress concentration should also be avoided in case that stress is too great for the material selected. The CAD model of the designed vibrator is constructed in Pro/ENGINEER and then exported to ANSYS.

A. Static Load Results

When the vibrating rod vibrates in the block which serves as the pivot of reciprocating vibration, a pressure of 12.5KPa is transmitted from the block to another part shown in Fig.6. The direction of the pressure is also shown in Fig.6. As expected, the stress is concentrated on the three bolt holes. The maximum stress calculated is 0.64 MPa. Because this is where the highest stress occurs and is where ANSYS determines the device would fail first, a redesign is required on the part. Another 2mm thick is added to where the bolt holes locate to strengthen the part. Fig.7 is the von Mises stress contour plot of the optimized design. The maximum stress calculated is only 0.38 MPa.

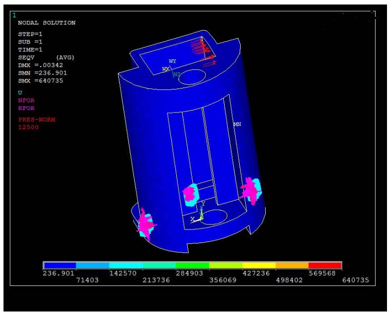

Fig. 6. Von mises stress contour plot.

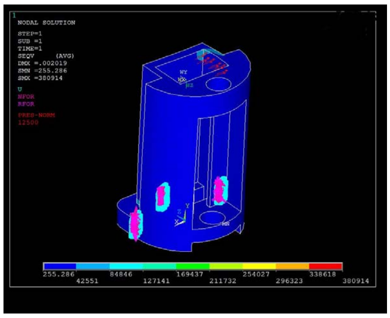

Fig. 7. Optimized design.

B. Modal Analysis Results

1) Whole Vibrator: To avoid resonance when the vibrator is used, modal analysis is made for the vibrator to optimize its natural frequency. The modal analysis results can provide valuable information about the dynamic response characteristics. The first three order natural frequencies of the designed vibrator are 751.86Hz, 1471.7Hz, 2385.6Hz. The maximum vibration frequency the motor can provide is about 250Hz, so resonance will not happen.

2) Vibrating Head: Fig.8 shows the vibrating head. The vibrating head contacts with the tooth when the vibrator is used. Then there will be an interactive force between them. Before contacting to the tooth, the vibrating head vibrates with a preset frequency which is the optimal frequency. Modal analysis was made to validate whether the generated force affected the vibrating frequency of the vibrating head. If the vibrating frequency (optimal frequency) is changed, the vibrator will not achieve its desired result. TABLE I shows vibrating head's the natural frequencies of six orders under different interactive forces between the vibrating head and tooth. It can be concluded that the natural frequencies change little within the range of 0N to 0.5N. So the force will not change the applied optimal frequency. The vibrator can work as expected.

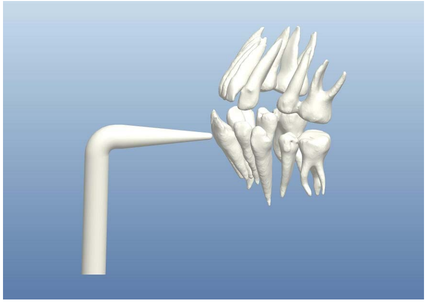

Fig. 8. Vibrating head.

TABLE I
NATURAL FREQUENCY OF VIBRATING HEAD

Mode	Natural Frequency (Hz)		
	0 N	0.1 N	0.5 N
1	203.81	203.75	202.20
2	211.80	211.72	209.89
3	582.60	582.55	581.89
4	725.19	725.18	724.93
5	1509.20	1509.00	1502.70
6	1716.80	1716.70	1710.80

IV. APPLICATION

The designed vibrator has two main functions, testing the natural frequency of TPBC and providing vibration of certain frequencies and intensities. Fig.1 has shown two cases of how to vibrate the tooth and collect the vibration signals. There will be a button of the vibrator to calculate the natural frequency and show the result. A regulating knob shown in Fig.3 can rotate the screw to adjust the vibration amplitude. Another regulating knob not shown is used to change the duty ratio of PWM, thus changing vibration frequency. Fig.9 shows the application example for the incisor. The left part is the measuring mode which measures the natural frequency of TPBC. The right part is the vibrating mode which applies vibration load to the incisor.

V. CONCLUSION

The designed vibrator can be used to test the natural frequency of TPBC. Besides, it can produce vibration of certain frequencies and intensities. The vibrator's main part was optimized by analysis in ANSYS, and the modal analysis verified modal frequencies were much higher than the operating range of the device, so they will not affect the operation of the device. And the interactive forces between the vibrating head and tooth make little difference to the applied optimal frequency. Since the optimal frequency applied to the tooth is relate to the natural frequency of TPBC, enough experiments are needed in the future to obtain the relation between them.

Fig. 9. Application of the vibrator.

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