DESIGN OF ORTHODONTIC WIRE HEAT TREATMENT APPARATUS

NANTIKA SRIPETCHWANDEE

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ABSTRACT

Heat Treatment is used to improve mechanical properties of orthodontic wires. In practice, dentists can perform heat treatments of wires by using commercial heat treatment devices, which are very expensive and difficult for inexperienced dentists to use.The objective of this study was to design and build a heat treatment apparatus which can be set to provide currents and times to heat-treat orthodontic wires automatically and appropriately to various sizes of stainless steel wires.

The voltage and current measurements of the heat treatments of the heat-treated wires at various times were utilized in the heat treatment apparatus design. Tensile and bending tests at various times were used for figuring out the time needed and mechanical properties of the wire.

For construction of the heat treatment apparatus, switching power supply was selected as a voltage generator to supply currents for the orthodontic wire heat treatment apparatus (a constant voltage at 6 volts and current between 1-15 amperes). The digital timer was used to control the heat exposition of orthodontic wires.

From the prototype testing in an actual scenario, the modulus of elasticity after heat treatment generally increased by approximately 10% or less. The effect of heat treatment on yield strength for orthodontic wires dramatically increased, generally, with percentage from 5% to 20%. The wires heated for 60 to 90 seconds had a smaller springback than the wires of comparable sizes heated for 10 to 50 seconds. This implies that lower amounts of heat produce orthodontic wires with better springback making them more suitable to dental work by their ability to last longer.

KEY WORDS: HEAT TREATMENT/ ORTHODONTIC WIRES

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เครื่องไฟฟ้าสำหรับปรับความร้อนแก่ลวดทางทันตกรรมจัดฟัน.
(DESIGN OF ORTHODONTIC WIRE HEAT TREATMENT APPARATUS).

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บทคัดย่อ

ปกติการให้ความร้อนแก่ลวดทางทันตกรรมจัดฟันนั้นจะช่วยเพิ่มคุณสมบัติทางกลศาสตร์ของลวดซึ่งในทางปฏิบัตินั้นทันตแพทย์จะให้ความร้อนแก่ลวดโดยใช้เครื่องที่ผลิตจากต่างประเทศซึ่งมีราคาแพงและไม่สะดวกในการใช้งานโดยเฉพาะสำหรับทันตแพทย์ที่ยังไม่มีความชำนาญเพียงพอ ฉะนั้นงานวิจัยนี้จึงมีวัตถุประสงค์เพื่อออกแบบและสร้างเครื่องมือให้ความร้อนแก่ลวดทางทันตกรรมจัดฟันที่สามารถใช้งานได้ง่ายเพียงแต่เลือกขนาดของกระแสไฟฟ้าและเวลาในการให้ความร้อนแก่ลวดให้เหมาะสมกับขนาดต่างๆของลวดที่ต้องการใช้

เพื่อประโยชน์ในการออกแบบเครื่องมือจึงจำเป็นต้องมีการวัดแรงดันไฟฟ้าและกระแสไฟฟ้าที่ใช้ระหว่างที่มีการให้ความร้อนแก่ลวด ณ เวลาต่างๆ รวมทั้งนำลวดนั้นไปทดสอบหาแรงดึงและการโค้งงอของลวดเพื่อหาเวลาที่เหมาะสมในการให้ความร้อนแก่ลวดขนาดต่างๆจุดประสงค์เพื่อให้ลวดมีคุณสมบัติตามที่ต้องการ ในส่วนของการสร้างเครื่องให้ความร้อนแก่ลวดนั้นจะใช้สวิตช์ชิ่ง เพาเวอร์ ซัพพลายเป็นตัวให้กระแสไฟฟ้าแก่เครื่องโดยกำหนดให้มีแรงดันไฟฟ้าคงที่ 6 โวลต์ และกระแสไฟฟ้าอยู่ระหว่าง 1-15 แอมแปร์ รวมทั้งมีการตั้งเวลาเพื่อควบคุมการให้ความร้อนแก่ลวดด้วย

จากผลการทดสอบเครื่องต้นแบบนั้น ค่าโมดูลัสของลวดหลังให้ความร้อนจะเพิ่มขึ้น 0% - 10% ส่วนความแข็งของลวดเพิ่มขึ้น 5% - 20% และสำหรับลวดที่ถูกให้ความร้อนที่เวลา 60 – 90 วินาที จะมีแรงดีดกลับของลวดน้อยกว่าลวดที่ถูกให้ความร้อนที่เวลา 10 – 50 วินาที ซึ่งแสดงให้เห็นว่าการให้ความร้อนที่เหมาะสมและไม่นานเกินไปจะเพิ่มแรงดีดกลับของลวดที่เหมาะกับการใช้งานทางทันตกรรมจัดฟันมากกว่า.

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CHAPTER I
INTRODUCTION

Orthodontic wires are designed for applying force to malaligned teeth in order to change their position/arrangements and to form more closely an ideal dental arch. The requirements of wires are related to their springiness, stiffness, formability, corrosion resistance, easily soldering, oral biocompatibility, and cost. Typically, optimal orthodontic tooth movement is produced by continuous light force. It should be importantly noted that does light force applied to teeth neither decreases rapidly nor decay away. Because, with high magnitude of force applied, the material itself loses its elasticity or a small amount of tooth movement causes a larger change in the amount of force delivered. Heat treatment therefore is used to enhance elastic properties of the wire. The magnitude of the applied force is important. The correct force depends on which type of tooth movement, five of which are tipping movement, rotational movement, translation movement, extrusion movement and intrusion movement is required, and on the geometry of the tooth roots [1].

For orthodontic purposes, three major properties of orthodontic wires are strength, stiffness / springiness, and range [2], which have an important relationship as:

$$\text{Strength} = \text{Stiffness x Range} \tag{1}$$

Strength is measured in stress units (gm/cm^2)

Stiffness and springiness are reciprocal properties as shown below:

$$\text{Springiness} = 1 / \text{Stiffness} \tag{2}$$

The range is defined as the distance that the wire will bend elastically before permanent deformation occurs. It is usually determined from 0.1% offset point on the force-deflection diagram. If the wire is deflected beyond its yield strength, it will not return to its original shape, but clinically useful springback will occur unless the failure point is reach as shown in Figure.1.

The springback for an orthodontic wire is given by equation (3)

$$\text{Springback} = \text{Yield strength} / \text{Elastic of Modulus} \tag{3}$$

$$= YS / E \tag{4}$$

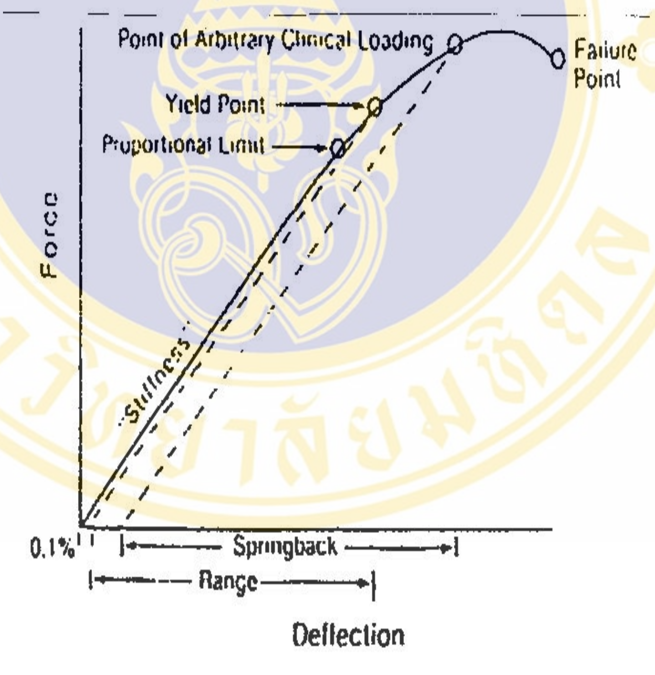


Figure 1 Typical force-deflection curve for an elastic material likes an orthodontic archwire. The slope of the linear portion of the curve gives the stiffness of the material. The range is the distance along the X-axis to the yield point, at which 0.1% permanent deformation has occurred. Clinically useful springback occurs if the wire is deflected beyond the yield point, but of course it no longer returns to the original shape. At the failure point, the wire breaks.

If the value of springback is high, it means that an orthodontic wire has a long working time. In a practical viewpoint, this means that a patient does not need to return frequently for readjustmenting an orthodontic wire. Springback characteristics of various wires are illustrated in Figure 2 [3], [4].

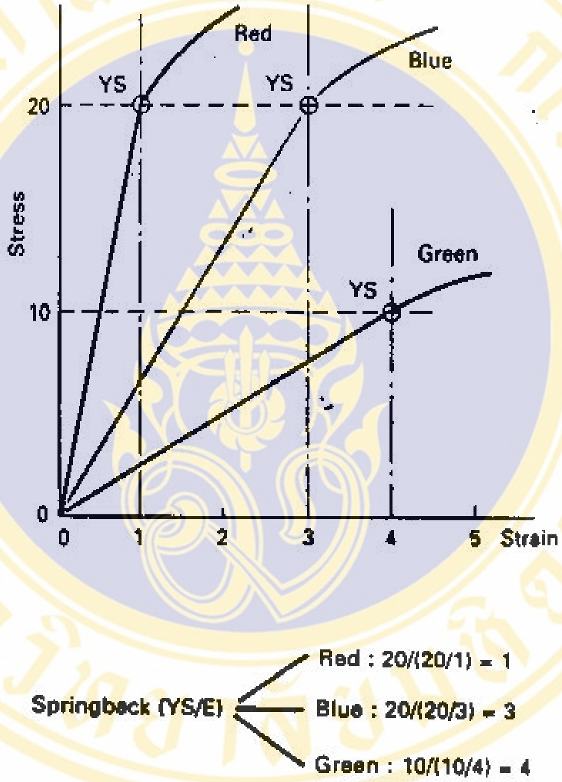


Figure 2 The red wire has a high yield strength (YS), but because it has a high elastic modulus its springback value is only 1. The blue wire has a similar yield strength, but because it has a lower elastic modulus, its springback value is 3. The green wire has a lower yield strength than the other two wire, but because it has an even lower elastic modulus, its springback value is 4.

Other properties, which are equally important to clinical characteristics are resilience and formability.

Resilience represents the energy storage capacity of the wire, which is a combination of strength and springiness or, in other words, the area under the stress/strain curve [5] which shown in Figure 3. High resilience means that the wire has a long working time, which also means the same as high springback value. Resilience can be expressed as:

$$\text{Resilience} = (\text{Yield Strength})^2 / 2(\text{Elastic of Modulus}) \quad (5)$$

$$= (YS)^2 / 2E \quad (6)$$

Formability represents the amount of permanent bending, which the wire will tolerate before it breaks as shown in Figure 3. High formability provides the ability to bend a wire into desired shape.

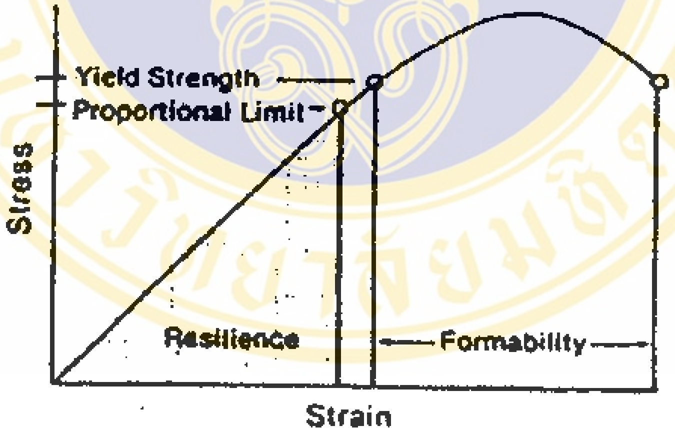


Figure 3 Resilience and formability are defined as an area under the stress-strain curve and a distance along the X-axis respectively, as shown here.

A wide variety of orthodontic wires such as stainless steel, titanium alloys (beta titanium, nickel titanium) and cobalt-chromium-nickel is used in dentistry. Modest increase in the modulus of elasticity can be obtained by suitable low temperature heat treatment of as-received wires. The effect of heat treatment on YS for the Elgiloy wires is quite dramatic with percentage increase generally from approximately 20% to 30% [3].

The improvement on the mechanical properties of E and YS for orthodontic wires following heat treatment ensures greater resilience and increased resistance to permanent deformation. The accompanying internal stress relief reduces the possibilities of premature fracture during clinical manipulation. It is well known that this microstructure is essential for an orthodontic wire to maintain the desired springiness; thus, optimum mechanical properties for clinical use.

Any heat treatment performed on the arch wire by a clinician to relieve residual stresses and to improve mechanical properties must not alter the wrought microstructure. For example, heat treatment of stainless steel wires at temperatures higher than 700° C (1300° F) causes rapid softening and deformation of the wire structure by the process of recrystallization. Optimum heat treatment would involve only the recovery stage of heat treatment [5].

In practice, clinicians can perform heat treatments of wire segments and appliances conveniently by using the appropriate portion of a commercial heat treatment apparatus.

Generally, the problems of a commercial heat treatment apparatus is that it is an imported product, which is very expensive, and that it is very difficult for an inexperienced dentist to proficiently choose an appropriate temperature of heat to avoid unnecessary damages to orthodontic wires. This leads to hidden costs and losses of efficiency in the heat treatment procedure.

1.2 Objective and Scope of This Study

The objective of this study is to design and build a heat treatment apparatus, which converts AC to DC current to be passed through an orthodontic wire for a defined period of time, causing a desirable change in its properties. A heat treatment increases yield strength, modulus of resilience, and springback properties of a stainless steel wire, which has the potential for a longer range of action to control the required tooth movement. The most important thing is that the apparatus should be convenient and simple enough to use by inexperienced dentists. For example, it must have time control feature to pass the current through the wire and cut off when the wire reaches its appropriate property.

In this study, stainless steel wires are used in the experiment because of their outstanding combination of mechanical properties, bioinertness and corrosion resistance in the oral environment, low cost, and widespread uses.

CHAPTER II
LITERATURE REVIEW

2.1 Introduction to Orthodontic Wires

The studies of orthodontic wires alloys have resulted in varied arrays of wires that exhibit a wide spectrum of properties. In 1930s, the only orthodontic wires were gold. Austenitic stainless steel, with its greater strength, higher modulus of elasticity, good resistance to corrosion, and moderate costs, was introduced as an orthodontic wire in 1929 [6]. Since then several other alloys with desirable properties have been developed in orthodontics. These include cobalt-chromium, nickel-titanium, beta-titanium, and multistranded stainless steel wires.

Nowadays, orthodontists may select one of all available wire types that best meets the demands of a particular clinical situation. The selection of an appropriate wire size and alloy type in turn would provide the benefit of optimum and predictable treatment results.

Several characteristics of orthodontic wires are considered desirable for optimum performance during treatment. These include a large springback, low stiffness, high formability, high stored energy, biocompatibility and environmental stability, low surface friction, and the capability to be welded or soldered to auxiliaries and attachment [2], [6].

Orthodontic wires are generally shaped by bending and the wires should possess sufficient ductility to resist fracture during this bending procedure. Each time the wire is bent, the metal becomes harder and more difficult to bend because of strain hardening. If the clinician is not careful, he or she could cause the wire to fracture before achieving the desired shape. This danger exists because with each bend it becomes more difficult permanently to change the shape of the wire. In other words, the wire is losing its ductility, or its ability to be permanently deformed; it becomes more brittle.

It is possible to eliminate the effects of strain hardening and return the metal to its original condition without altering its shape. At high temperature (although still far below the melting range), atomic rearrangements relive the stress imposed by the bending process, thus recovering the ductility of the metal and allowing further bending without the potential for fracture. This heating process, called heat treatment, can be used to eliminate the effects of strain hardening while maintaining the shape of the metal [7]. An orthodontic wire that has been extensively shaped can be heat-treated by heating it in an oven or over a flame at several hundred degrees Celsius for several minutes, with resulting atomic rearrangement. If the time used is too long or the temperature is too high, the wire will be over softened and be less efficiency in moving teeth. This stage is called annealing.

2.2 Mechanical Properties

There are five basic mechanical properties of orthodontic wires that are directly considered during treatment [2], [8].

2.2.1 Stiffness or Load Deflection Rate

Stiffness, the force magnitude delivered by an orthodontic wire, is proportional to the modulus of elasticity (E). Stiffness is represented by the slope of the graph . (Young's Modulus) which shown in Figure 4. This graph presents that wire A is stiffer than wire B. The stiffness of a wire indicates the maximum force which the wire could deliver. Although differing in stiffness, wire A and B have identical range. Low stiffness provides the ability to apply little force, a more constant force over time as the orthodontic wire experiences deactivation, greater ease and accuracy in applying a given force.

2.2.2 Springback or Working Range

Springback is related to the ratio of yield strength to the modulus of elasticity of the material (YS/E). In Figure 4, although their stiffness is identical wire D has a greater range than wire C. High springback values provide the ability to apply large activations, thus, increasing the working time of the orthodontic wire. Springback is also a measurement of how far a wire can be deflected without causing permanent deformation or exceeding the limits of the material.

2.2.3 Strength

Strength is a measurement of the maximum force, which can be applied by the wire at the upper limit of its elastic range. According to Figure 4, wire E has a greater strength (and range), but less stiffness than wire F. Strength is represented by stiffness multiplied by range.

2.2.4 Resilience

This property represents the capability of an orthodontic wire to move teeth. It is a measurement of the force storage capacity of the wire, and the area under the graph reflects it. In Figure 4, wire G has a greater resilience than wire H. The two wires have identical strength, but wire G has a greater range than wire H.

2.2.5 Formability

High formability provides the ability to bend a wire into desired configurations, such as loops and coils, and to stop without fracturing the wire as shown in Figure 4.

The three important elastic properties of arch wire materials are stiffness, range (springback) and strength. These properties are affected by a change in diameter and length of a wire.

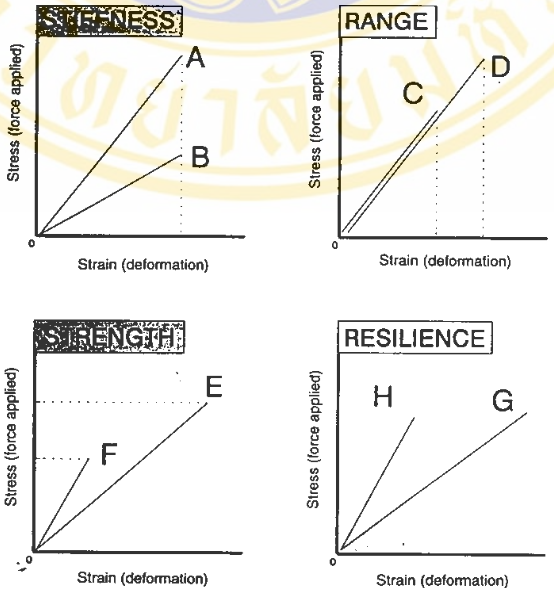


Figure 4 Stiffness, range, strength and resilience of wires.

2.3 Recovery Heat Treatment

The effects, such as strain hardening, lowered ductility, and distorted grains which are associated with cold working from the manufacturer can be eliminated by heating the metal. This process is called heat treatment. Generally, heat treatment comprises three stages: recovery, recrystallization and grain growth [5]. The effects of these three stages upon the tensile strength and ductility of a metal are shown in Figure 5.

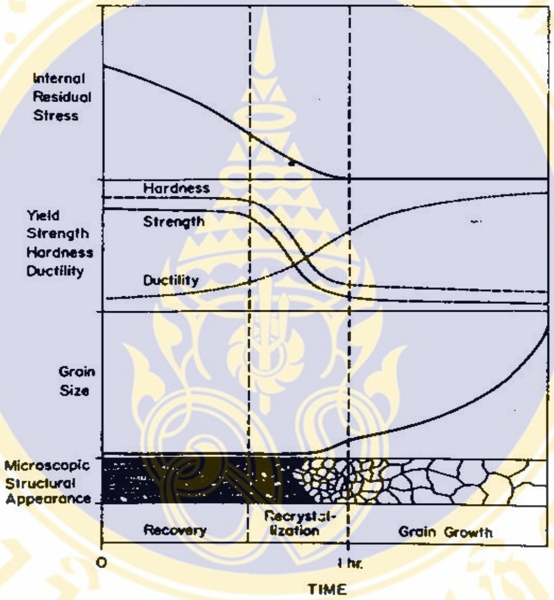


Figure 5 A microscopic view of the stages that a cold-worked metal, such as an orthodontic wire, goes through when subjected to prolonged heating. The higher the temperature and the greater the Cold working, the more quickly the transitions occur. This figure shows recrystallization being complete in one hour, which means that the temperature of heating was the recrystallization temperature as per the definition. The changes in properties can be compares with the structure change.

Any heat treatment performed on the archwire to relieve residual stress and improve mechanical properties must not alter the wrought microstructure. Optimum heat treatments would involve only the recovery stage of heat treatment. If heat treatment is to be performed, it should be held to temperature between 400 and 500 °C for various lengths of time from about 5 to 120 seconds, depend on the temperature, type of orthodontic wire being heated [9]. A stress relief heat treatment not only improves the working elastic properties of a wire but can also reduce failure due to corrosion, which may occur in area of high localized stress.

2.4 Stainless Steel Wires

Stainless steel wires are constructed from the 18/8 austenitic type of stainless steel containing less than 0.15 % carbon. The wires most commonly used are type 302 and 304 [3], [5]. The wires which used in this study are stainless steel type 304 which is composed of 18% to 20% chromium, 8% to 10.5% nickel, and 0.08% maximum carbon. The advantages of stainless steel are cheap, strong, resilient, easy to manipulate and not affected by the oral fluid [10].

Mechanical properties of stainless steel orthodontic wires listed in Table 1 show two sizes of wires in as-received and stress-relieved conditions. The higher values of proportional limit and yield strength of the 0.014 inch diameter wire reflects the increased amount of cold-working used to fabricate this size of wire compared to the 0.022 inch diameter wire. The properties of these wires (except tensile strength) are improved by the stress-relieving heat treatment.

Table 1 Mechanical properties of 18-8 stainless steel wires [9]

	0.014-inch diameter		*0.022-inch diameter*	
Property	*As received*	*Stress relieved†*	*As received*	*Stress relieved†*
Proportional limit,‡MN/m^2(10^3 lb/inch^2)	1200 (174)	1380 (200)	1060 (153)	912 (132)
Yield strength, 0.1% offset, ‡ MN/m^2 (10^3 lb/inch^2)	1680 (243)	1950 (282)	1490 (216)	1640 (238)
Tensile strength, MN/m^2(10^3 lb/inch^2)	2240 (324)	2180 (317)	2040 (296)	2160 (312)
Hardness (Knoop), kg/mm^3	525	572	536	553
Cold-bending, number of 90-degree Bends	37	45	13	21

*Adapted from Craig. R.G., editor: Dental materials: a problem oriented approach. St. Louis. 1978. The C.V. Mosby Co.

† Heated at 482º C (900º F) for 3 minutes.

‡ Properties are measures in tension

The effect of heating on the bending moment-angular deflection curves for round stainless steel wire is shown in Figure 6. Heating the wire for a short time (15 seconds) causes low stiffness. Thus, it can be easily bent and can be made into more angular deflection to the as received wire [9].

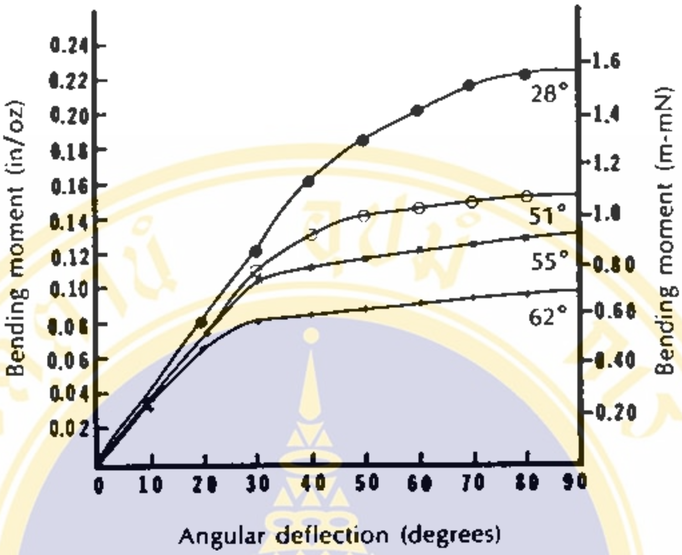


Figure 6 Bending moment-angular deflection curves for 0.018-inch diameter 18-8 stainless steel wire in the as received condition (…) and after 15 seconds (ooo), 60 seconds (xxx), and 120 seconds (+++) at 816° C (1500° F).

2.5 Study of Constant Voltage Power Sources

Normally, power supply is composed of transformer, rectifier and filter as shown in Figure 7. The voltage of the power supply must be fixed with minimum ripple by the voltage regulator [11], [12]. The regulated power supply technology can really be divided into two distinct forms; firstly, the linear or series regulator and, secondly, the switch-mode conversion technique.

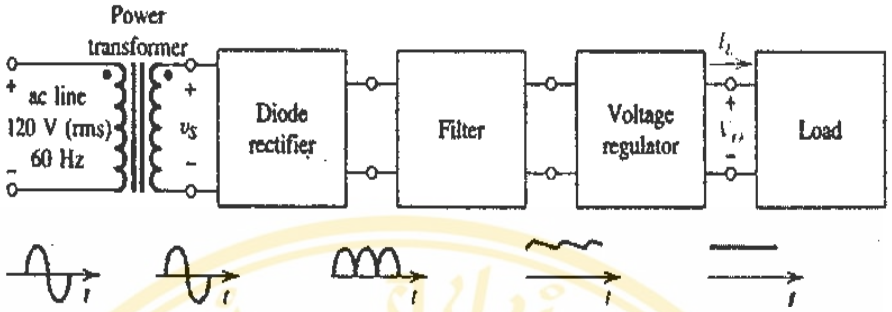


Figure 7 Block diagram of a Dc power supply

The main differences between the linear and switch-mode regulator are in the size, weight and efficiency. The linear regulator, Figure 8, utilizes simple techniques of controlled energy dissipation to achieve a regulated output voltage independent of line and load variation. It is, therefore, inherently inefficient, especially when a wide input voltage range has to be catered for. When linear technique are applied to regulating a low voltage from the mains 110 V or 240 V [13].

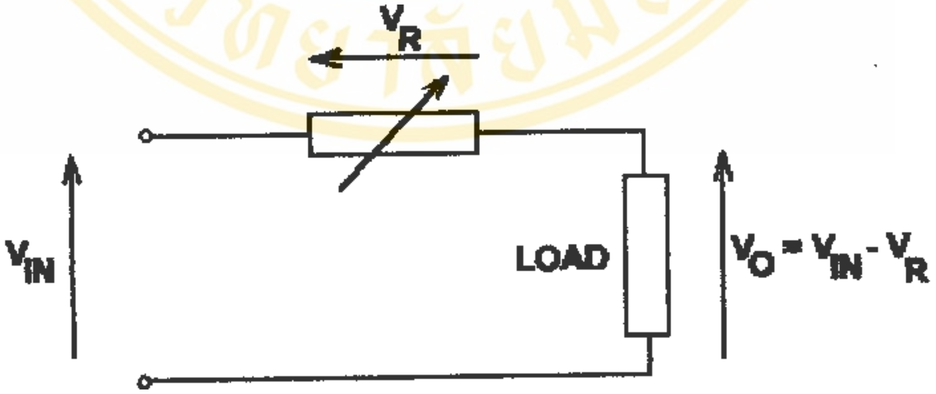


Figure 8 Linear series Regulator Equivalent Circuit.

A typical linear power supply is shown in Figure 9. The step down, low frequency main transformer is very bulky, large heat-sink is required to dissipate the heat generated by the regulating elements and very large filter capacitors are required to store enough energy at the voltage to maintain the output for a reasonable length of time when the main source is removed. Linear power supplies are simple and inexpensive. They provide excellent line regulation and transient response to changes in load. They tend, however, to be bulky and heavy because poor efficiency (<40%) limits their power density ($<0.12W/cm^3$ or $2W/in^3$). Linear regulation and power supplies fit best in low-power situations that demand very "clean" power. Switched-mode techniques, on the other hand, offer the possibility of theoretically loss-less power conversion. The switch-mode regulator, Figure 10, employs duty cycle control of a switching element to block the flow of energy and thus achieve regulation. It has the added advantage of when applied to off-line applications of giving significant size reduction in the voltage transformer and energy storage elements.

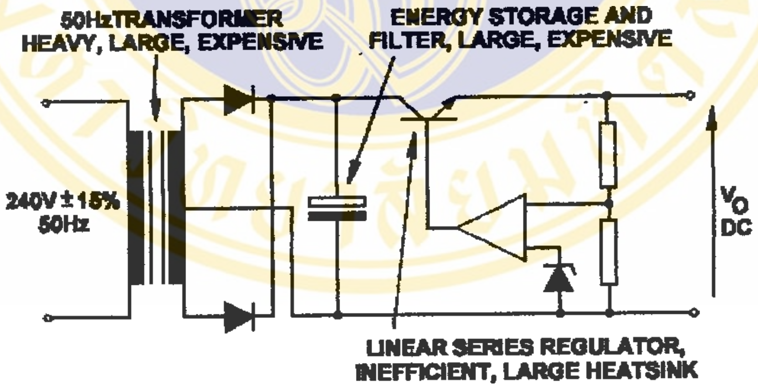


Figure 9 Practical Linear Series Regulator Circuit.

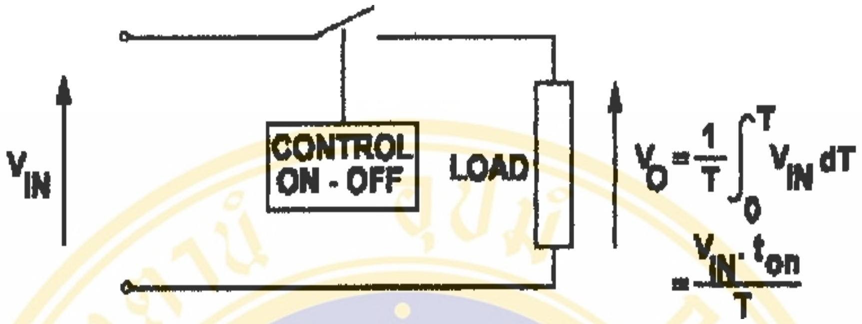


Figure 10 Switched-Mode Regulator Equivalent Circuit.

Since a switched-mode converter can operate at significantly high frequencies, then a smaller transformer using ferrite cores can be used. Also since the high-rectified main voltage is chopped, then energy storage for hold-up can be accomplished on the primary side of the step-down transformer and so much smaller capacitors than the linear counterpart can be used. As shown in Figure 11 below.

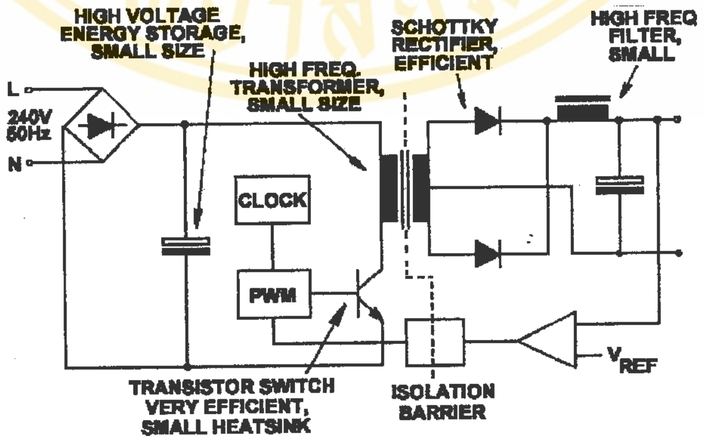


Figure 11 Practical Circuit of a Switched-Mode Regulator.

Switching power supplies can have excellent efficiency (>95%) and high power density W/cm^3 or 100W/in^3). They can accept wide variation of input voltage (>100%) and frequency (>100%) and generally have good line regulation and transient response. They can be very small and light. Switching power supplies tend, however, to be more complex and expensive than linear supplies and power factor correction must be added in many applications. Switching power supplies fit best in situations that require efficient power conversion.

Although the benefits of switched-mode techniques are great, there is a penalty paid in the increased noise present at both input and output of the supply due to the power switching techniques. Also the associated control circuitry is much more complicates than its linear counterpart.

CHAPTER III
MEASUREMENT FOR DESIGN CRITERIA

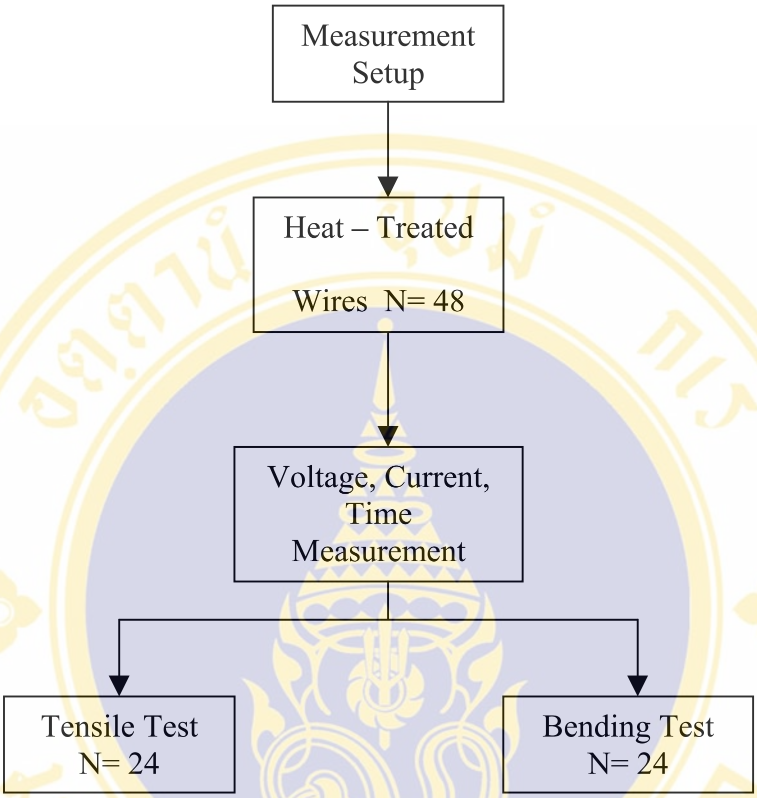
3.1 Purpose

Heat treatment, as seen in the previous chapter, is critical to orthodontic wire properties and to the qualities of dentists in handling manually the heat treatment. It is thus decided to design a heat treatment apparatus that can automatically take over dentist's manual roles in the treatment of orthodontic wires as much as possible.

The study is conveniently begun by making use of an available heat treatment apparatus, the TOMY model Arch-Mate NO. 47-900-02, in order to find out certain data, which can be utilized in handling it manually. Electrical measurements, while operating the existing equipment with a given set of orthodontic wires, are hoped to enable one to gain valuable data, to design, and to construct an automatic heat treatment apparatus for the requires purposes.

3.2 Measurement Setup

The study began with the heat treatment apparatus, TOMY model Arch-Mate NO. 47-900-02, in finding out the current and the voltage during the heat treatment of the wires. The objective is to collect the data for apparatus's design criteria.



3.2.1 Heat-Treated Wires Measurement

The voltage and current measurements of the heat-treated wires at various times are utilized in the heat treatment apparatus design. The tensile and bending test at various times are used for figuring out the time needed and mechanical properties of the wire.

3.2.2 Materials

1. The heat treatment apparatus, TOMY model Arch-Mate NO. 47-900-02.
2. Wire sizes used: 0.014”, 0.016”, 0.018”, 0.016”x0.022”, 0.017”x0.025”, 0.018”x0.025” in diameters and 7” in length, 8 pieces per wire size.
3. Two multimeters.

4. The Instron Corporation Series IX Automate Materials Testing System at National Metal and Materials Technology Center.

3.2.3 Methods

1. Measure all wire's resistance by multimeter.
2. For voltage measurement, one multimeter connected in parallel with the heat treatment apparatus.
3. For current measurement, another multimeter connected in series with the circuit see Figure 12.
4. Various times, 3s, 5s, 7s and 9s, are used for finding the time needed to heat the wire to reach the desired properties. Two pieces of wire are heat-treated for a given time.
5. Tensile test for 24 pieces of heat-treated wires (4 pieces/size) is made by using The Instron Corporation Series IX Automate Materials Testing System at National Metal and Material Technology Center.
6. Bending test for 24 pieces of heat-treated wires (4pieces/size) is made by using The Instron Corporation Series IX Automate Materials Testing System at National Metal and Material Technology Center.

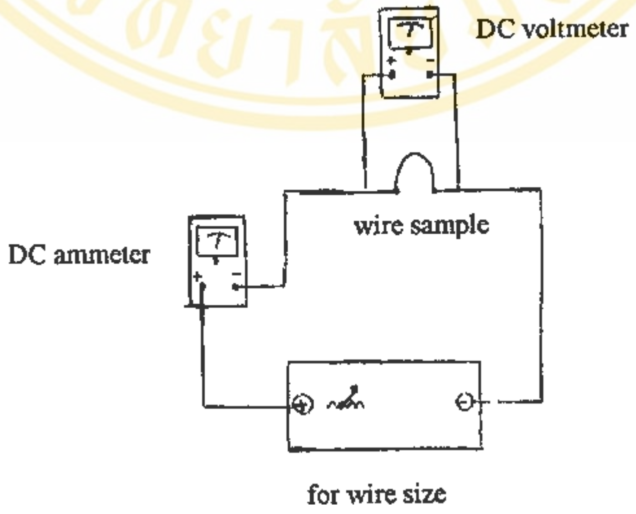


Figure 12 Test setup diagram.

3.3 Results

3.3.1 As-received Wire's Resistance Measurements

Resistance of Ormco's stainless steel wires 7" in length were measured by using Fluke 87 RMS multimeter the results are shown in Table 2 below:

Table 2 Resistance of Ormco's Stainless Steel Wires.

Diameter (inch)	1 (ohms)	2 (ohms)	3 (ohms)	4 (ohms)	5 (ohms)	6 (ohms)	Average (ohms)
0.014	2.2	2.4	2.3	2.2	2.3	2	2.23
0.016	1.6	1.5	1.9	1.7	2	1.8	1.75
0.018	1.5	1.5	1.4	1.5	1.5	1.9	1.55
0.016x0.022	1.2	1	1.1	1.2	1	1	1.1
0.017x0.025	0.9	1	1.1	1.1	1.1	1.1	1
0.018x0.025	1	0.9	0.9	0.9	1	0.9	0.95

3.3.2 Voltage and Current Measurements during Heat Treatment of Wires

Voltage and current measurements during heat treatment of wires were carried out with TOMY model Arch-Mate NO. 47-900-02 at various times, using SANWA CD 800 digital multimeter and DMM DT9207 digital multimeter. Voltage and current of each 7-inch Ormco's stainless steel wire were measured as shown in Table 3 below:

Table 3 Voltage and Current Measurements during Heat-Treated.

Diameter (inch)	Time (s)	I (A)	Voltage (V)
0.014			
NO.1	3	2.63	6.08
NO.2	3	2.75	6.15
NO.1	5	2.62	6.15
NO.2	5	2.52	6.15
NO.1	7	2.43	6.15
NO.2	7	2.45	6.15
NO.1	9	2.32	6.15
NO.2	9	2.28	6.15

Table 3 Voltage and Current Measurements during Heat-Treated. (continued)

Diameter (inch)	Time (s)	I (A)	Voltage (V)
0.016			
NO.1	3	3.03	5.89
NO.2	3	3.02	6.05
NO.1	5	3.02	6.06
NO.2	5	3.01	5.86
NO.1	7	3	6.08
NO.2	7	2.91	6.08
NO.1	9	2.92	6.07
NO.2	9	3	5.9
0.018			
NO.1	3	3.35	5.05
NO.2	3	3.39	4.87
NO.1	5	3.43	5.23
NO.2	5	3.38	5.22
NO.1	7	3.45	5.12
NO.2	7	3.48	5.01
NO.1	9	3.49	5.04
NO.2	9	3.5	5.08
0.016x0.022			
NO.1	3	5.2	6.12
NO.2	3	5.37	6.12
NO.1	5	5.18	6.12
NO.2	5	5.18	6.12
NO.1	7	5.06	6.12
NO.2	7	4.98	6.12
NO.1	9	4.92	6.12
NO.2	9	4.46	6.12
0.017x0.025			
NO.1	3	5.78	6.11
NO.2	3	5.77	6.11
NO.1	5	5.57	6.11
NO.2	5	5.72	6.11
NO.1	7	5.43	6.12
NO.2	7	5.48	6.12
NO.1	9	5.43	6.12
NO.2	9	5.37	6.12

Table 3 Voltage and Current Measurements during Heat-Treated. (continued)

Diameter (inch)	Time (s)	I (A)	Voltage (V)
0.018x0.025			
NO.1	3	6.39	6.1
NO.2	3	6.31	6.1
NO.1	5	6.27	6.11
NO.2	5	6.04	6.1
NO.1	7	5.95	6.1
NO.2	7	5.93	6.1
NO.1	9	5.93	6.11
NO.2	9	5.82	6.1

3.4 Discussion

It may be concluded that it is possible to design and construct an automatic heat treatment apparatus for orthodontic wires by using a constant voltage generator to supply varying current on demand by the various orthodontic wire diameters. Moreover, the apparatus should be able to set the required currents by selecting the size of wires and the required time for dentists to choose with a time-increment feature. The apparatus should have a main pilot lamp and working pilot lamp indicators for double check before the start to execute a treatment.

CHAPTER IV
MATERIALS AND METHODS

4.1 MATERIALS

In order to complete the project, access to certain resources is required.

4.1.1 The Heat Treatment Apparatus

Development of Heat Treatment Apparatus was done with the use of:

- Switching power supply : S-100-5
- Digital timer : UN-6A
- Resistors
- Ammeter
- Pilot lamps
- Fuse

4.1.2 Testing of Prototype Apparatus

- Wire size used: 0.014”, 0.016”, 0.018”, 0.016” x 0.022”, 0.017” x 0.025”, 0.018” x 0.025” in diameter and 7” in length, 40 pieces per wire size.
- The Instron Corporation series IX Automate Material Testing System at National Metal and Materials Technology Center (See Figure 13).

Figure 13 The Instron Corporation series IX Automate Material Testing System.

4.2 METHODOLOGY

The design and construction of Orthodontic Wire Heat Treatment (OWHT) Apparatus is carried out in 2 stages: stage 1 for collecting data from an available Orthodontic Wire Heat Treatment Apparatus, the TOMY model Arch-Mate NO. 47-900-02 which can be utilized in the design concept of an apparatus as seen in the previous chapter and stage 2 for testing the OWHT Apparatus so constructed in actual scenario in order to assessing its suitability to the required dental works.

4.2.1The development process can be divided into 3 principal steps as follows:

Data collecting and related document review

- To understand the orthodontic treatments in order to integration it into the project.
- To study the properties of orthodontic wires before and after heat treatment in order to integration it into the project.
- To collect data from an available Heat Treatment Apparatus, the TOMY model Arch-Mate NO.47-900-02, for designing and constructing a prototype apparatus.
- To study the constant voltage power sources for designing into a prototype apparatus.

4.2.2 Design study

The basic elements of the prototype apparatus are shown in the Table 4.

Table 4 Circuit Components.

Circuit components	Function
1. Switching Power Supply	Used to provide the energy
2. Digital Timer	Time control
3. Ammeter	Used to measure the current
4. Resistors	Used to control the current
5. Fuse	Used to prevent the power supply damage

Discussions of these components are made in details with a view to select suitable components to be built into an OWHT Apparatus as described below:

1. Power Supply

For every electric application there must be a reliable power source. The power supply is one of the most critical components of any electrical system. Some design considerations are size, cooling for the power supply, input voltages, output voltages, output regulation, reliability, and relative cost.

A power supply is a buffer circuit that provides power with the characteristics required by the load from a primary power source with characteristic often incompatible with the load. The concept is to make the load compatible with its power source.

The types of regulated power supply that can be used are:

- Linear power supply which using transistors for voltage control and ripple reduction.
- Switching power supply that uses transistors as switching to generate high frequency modulation.
- Ferroresonant power supply where a constant voltage transformer controls voltage and reduces ripple.

The constant voltage transformer in ferroresonant regulation is large, heavy and usually constrains it to ground installation for uninterruptible power supplies. Typically, most applications incorporate both linear power supply and switching power supply.

One advantage of linear power supplies is it has been commonly used among technicians and/or engineers, because they have been available for many years. They are known to be relatively noise-free and reasonably reliable. Their design is easy and their manufacturing cost is low.

However, linear power supplies are generally large and heavy due to the transformer. Because of the large transformers required, linear power supplies are generally heavy, which have both advantage and disadvantage, depending on the need to balance the weight distribution in a given application. A possible disadvantage of linear power supplies relates to the power transistor being used to regulate the load. Because the power transistor operates in its linear region, and all the output current must pass through it, it requires large heat sinks to dissipate energy loss. Except in rare instances where heat is wanted to warm interior space, the inefficiency of linear power supplies_50%_has to be considered a disadvantage.

Although switching power supplies have been available for a number of years, higher production costs, compared to linear power supplies, have limited their use in some applications. Early switching power supplies used discrete components to control pulse width, and transistors instead of MOSFETs as main switching components. As a result, the disadvantages of switching power supplies are uneven reliability and radiated EMI (electrical noises). Nonetheless they are known to be noisy, unreliable and difficult to mass-produce. And they are advantage in being lighter and smaller than their linear counterpart, in addition production costs have come down because application-specific components are being designed for use in switching power supplies.

Fortunately in the last few years, big improvements in PWM and MOSFET design have been made and all design considerations have been taken into account, switching power supplies are highly reliable and virtually noise-free.

Switching power supplies are about 80%-90% efficient. Higher efficiency usually is an advantage, because the heat is normally considered to be a wasted energy (at the least) and a potentially damaging to nearby electronic components. The main advantages of switching power supplies have more efficiency and thus lower dissipation than linear one [14]. Coupled with the smaller size per watt, switching power supplies are ideal for application where panel density is high.

According to this project, the switching power supply, S-100-5, was selected as a voltage generator to supply currents for the OWHT Apparatus. It is reasonably smaller in size and lighter in weight, less heat generation, higher efficiency (a constant voltage at 6 volts and current between 1-15 Amperes) and inexpensive in cost.

2. Digital Timer

This timer; UN-6A, is considered suitable for the prototype apparatus. It is used to control heat exposition of orthodontic wires. UN-6A is a digital timer displayed by 4-digit LCD with built in backlight. The timer can be set digitally within a range from 0.001 second to 9999 hours. Its function can be selected in many operating modes. In this project, it uses the addition (count-up) mode within the range from 000.1 seconds to 999.9 seconds for timing the heating duration.

3. Ammeter

Ammeter is a current- sensitive device that is inserted in the circuit. By adding several shunt resistors in the metering case, with a switch to select the desired resistor. The ammeter will be capable of measuring several different maximum current . Since a shunt resistor is used to protect ammeter from getting over current and to allow accurate measurement, it is important that the resistance of the shunt resistor is known very accurately. For limited current ranges (1-15 amperes), internal shunts are most often employed. Therefore, ammeter with shunt resistors was selected as an application tool for this project.

4. Resistor

A resistor is a device that limits the amount of current flowing though a circuit for a particular applied voltage. There are two classes of resistors; fixed resistors and variable resistors. A fixed resistor is one in which its resistance cannot be changed, but a variable resistor has a dial or knob for resistance changing. The resistance value of the resistor is not the only thing to consider when selecting a resistor for use in the circuit but the “tolerances” of the resistor are also important. The tolerance of a resistor denotes how precision it is comparing to the actual resistance value. Cement resistor is a fixed resistive resistor used in this project. Usually the tolerance of the resistance value is ± 1%, small, sturdy, and reliable. Moreover, it has a high temperature stability and an excellent moisture resistance.

5. Fuse

Electrical applications occasionally have short circuit situations. The most basic process for preventing damage to the power supply is to use a fuse. Each types of fuse is designed for a specific amount of current. As long as the current in the circuit is kept below this value, the fuse passes the current with little opposition. If the current rise above the rating of the fuse due to malfunction or short circuit the fuse will “blow up” and disconnect the circuit.

How does the prototype apparatus works?

The basic elements of the prototype apparatus are shown in Figure 14 below, together with its circuit block diagram. These are the switching power supply, wire selection knob, digital timer, ammeter and fuse.

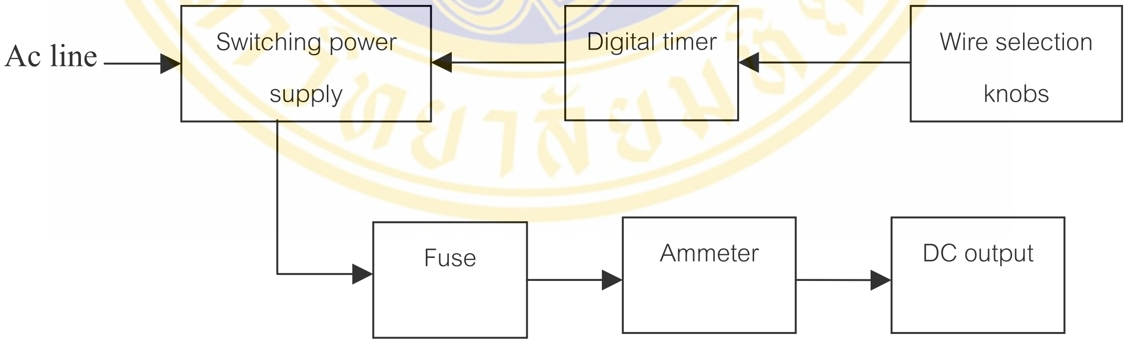


Figure 14 OWHT Apparatus and its circuit block diagram.

The AC line is converted from 220 Vac to 6 Vdc by the switching power supply. The wire selection knob ensures that the current is controlled at one of the 4 levels as required for each heat treatment of an orthodontic wire. Similarly, the optimal time for heat treatment of each wire is controlled by the digital timer, which is set to operate in count-up mode. At this point, it is necessary to find out the optimal time for each wire size. When switch is on, the current passing through orthodontic wire is measured by the ammeter. If excessive current is flowing in the circuit, the fuse will literally burn up or melt, causing a physical gap in the circuit and saving the device from the high-current damage.

Figures 15 and 16 shown the photograph of the finished OWHT apparatus together with its interior layout.

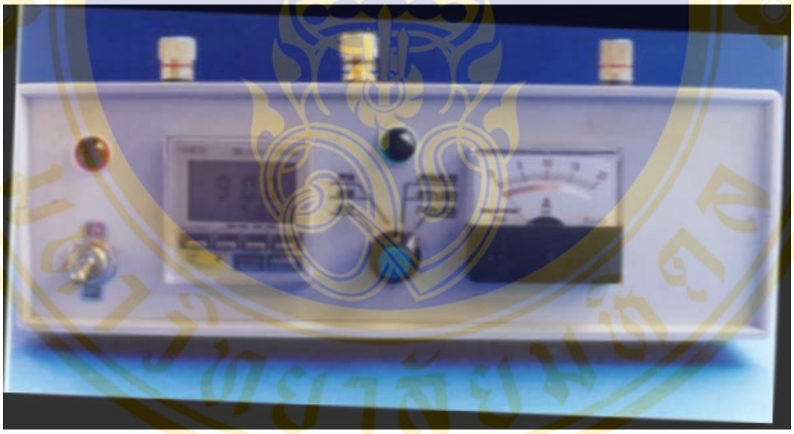


Figure 15 The photograph of the OWHT Apparatus as developed and built for this study.

Figure 16 An interior of the OWHT Apparatus as developed and built for this study.

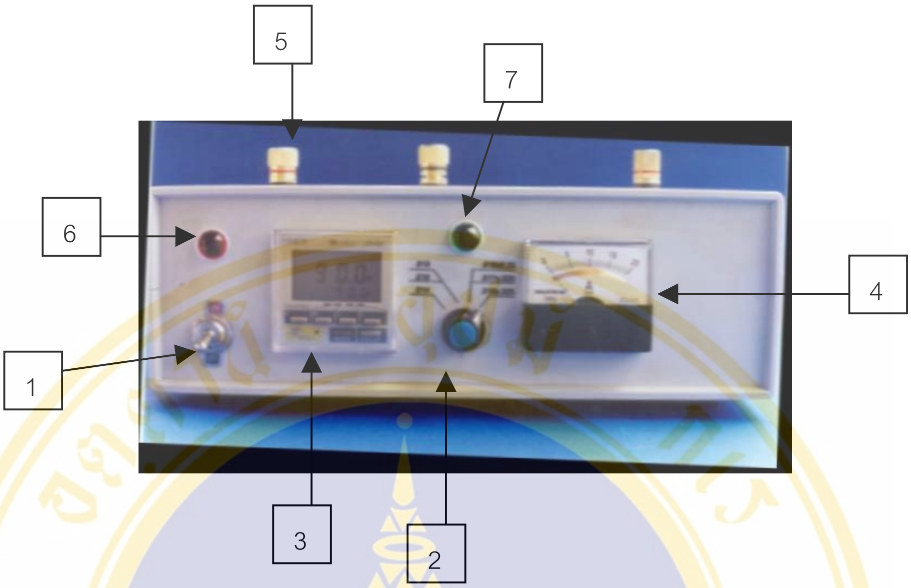


Figure 17 Layout of the OWHT Apparatus.

The prototype components (Figure 17):

1. On/Off switch.
2. Wire size selection knob.
3. Digital timer.
4. Ammeter.
5. Wire's connection.
6. Red lamp: This lamp is lit at switching on.
7. Green lamp: This lamp is shown when the apparatus is operating.

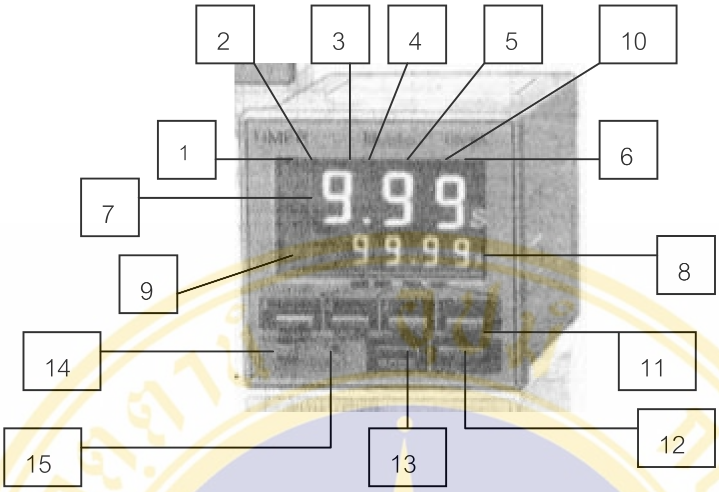


Figure 18 Digital Timer Components.

Digital Timer Components (Figure 18):

1. Power Display.
2. Input Signal Display.
3. Reset Signal Display.
4. Gate Signal Display.
5. Key Pad Lock Display.
6. Output Signal Display.
7. Time Counter.
8. Time Setting.
9. Mode Display.
10. Operating Display.
11. Set Button.
12. Display Button.
13. Mode Button.
14. Reset Button.
15. System Reset Button.

Digital Timer Programming:

Figure 19 shows the flow-chart diagram of digital timer programming.

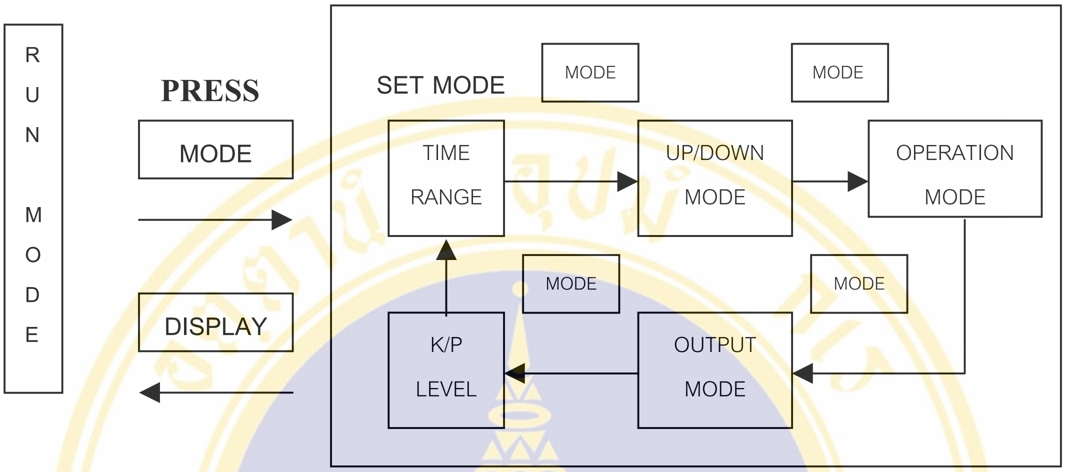


Figure 19 Flow Chart Diagram of Digital Timer.

Direction to use:

1. Connect the plug of power line firmly into the socket, and press RESET button.
2. Select the Orthodontic wires to be heat-treated and connect or clamp it to the suitable terminals provided.
3. Select the knob for each wire size:

   0.014”.

   0.016” and 0.018”.

   0.016” x 0.022” and 0.017” x 0.025”.

   0.018” x 0.025”.
4. To adjust the timer :

   Press the hold/time button for each digit 1,2,3,4 in a range from 000.1 to 999.9 seconds. Don’t forget to push the “RESET” button to be ready for the next operation.
5. Push the ON/OFF switch to “ON” to start the operation.

   Push the ON/OFF switch to “OFF” when the operation is completed.

4.2.3 Testing of the OWHT Apparatus

This phase involves tensile and bending tests of heat-treated wire. Sizes of wire are selected by integers such as 1 for 0.014" and 2 for 0.016". The digital timer is then set at the required time and the apparatus is then switched on. Tensile and bending tests are used to evaluate the properties of heat-treated wires for comparison with as-received wires of the same kind and size.

Various times (10 s, 15 s, 20 s, 30 s, 40 s, 50 s, 60 s, 75 s and 90 s) for heat treatment are investigated to find an optimum time needed to heat the wire to reach the desired properties. 216 pieces of wire are heat-treated for a given time. Then, tensile and bending test for 216 pieces of heat-treated wire (36 pieces per size) are made by using the Instron Corporation Series IX Automate Materials Testing System at the National Metal and Material Technology Center. The series of tests can be summarized as shown in Fig. 20. Finally, the wires from the same batch of wires under test are evaluated in actual scenario in order to assess their suitability for the required dental works by an orthodontist.

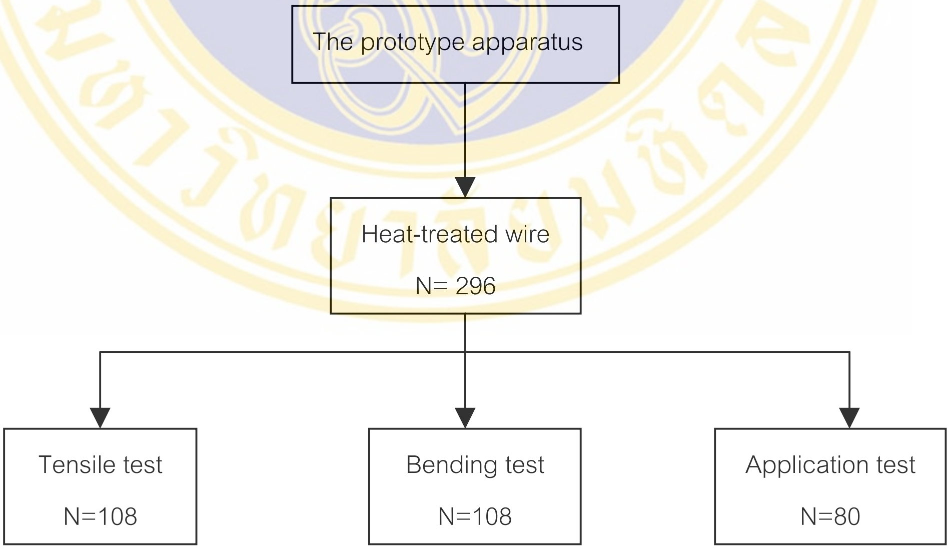


Figure20 The OWHT Apparatus testing diagram.

Application Test

The application test is a special test as in actual scenario. Forty pairs of orthodontic wires, as received and heat-treated, of the sizes ranging from 0.014”, 0.016”, 0.018” to 0.018” x 0.025” in diameter and 7” in length were stretched by the Instron Corporation Series IX at Faculty of Dentistry Mahidol University in order to measure their deformity after the release of stretching force.

CHAPTER V
RESULTS

The 216 pieces of orthodontic wires of the sizes ranging from 0.014”, 0.016”, 0.018”, 0.016” x 0.022”, 0.017” x 0.025” to 0.018” x 0.025” in diameter and 7” in length were heat-treated at various times. Preheated resistances of the wires are measured and shown in Table 5, together with the average currents used in heat treatment.

Table5 Average preheated Resistance and Average Heating Current.

Diameter	Pre-heated Resistance	Average Heating Current
(inch)	(Ohm)	(Ampere)
0.014	2.23	2.5
0.016	1.75	3
0.018	1.55	3
0.016x0.022	1.05	4
0.017x0.025	0.93	4.5
0.018x0.025	0.88	4.5

The result shows that the average current was higher in large wires than in smaller wires as expected since higher resistances of small wires need lower currents to give the same amount of heat as required by larger wires.

Values for maximum strength, Yield strength and modulus of elasticity in tension tests for the as-received and heat-treated wires as measured by Instron Corporation Series IX System are given in Table 6 for comparison.

Table 6 Comparison of maximum strength, yield strength and modulus of elasticity obtained in tension for as-received and heat-treated wires.

Tension Test					
Wire Type	Diameter (inch)	Time (seconds)	Max. Stength (MPa)	Yield Stength (MPa)	Modulus (MPa)
As-received*	0.014		2207	1792	108100
Heat-treated	0.014	10,15,20	2339	2215	124099
Heat-treated	0.014	30,40,50	2332	2124	115159
Heat-treated	0.014	60,75,90	2277	1874	111019
As-received*	0.016		2216	1768	107050
Heat-treated	0.016	10,15,20	2217	2169	121716
Heat-treated	0.016	30,40,50	2196	1943	113366
Heat-treated	0.016	60,75,90	2307	1833	108966
As-received*	0.018		2353	1707	109507
Heat-treated	0.018	10,15,20	2439	2110	125714
Heat-treated	0.018	30,40,50	2333	1994	116296
Heat-treated	0.018	60,75,90	2383	1806	113559
As-received*	0.016x0.022		2165	1666	107000
Heat-treated	0.016x0.022	10,15,20	2214	2058	121338
Heat-treated	0.016x0.022	30,40,50	2332	1921	112029
Heat-treated	0.016x0.022	60,75,90	2122	1756	109996

Table 6 Comparison of maximum strength, yield strength and modulus of elasticity obtained in tension for as-received and heat-treated wires.(Continued)

Tension Test					
Wire Type	Diameter (inch)	Time (seconds)	Max. Stength (MPa)	Yield Stength (MPa)	Modulus (MPa)
As-received*	0.017x0.025		2157	1652	106400
Heat-treated	0.017x0.025	10,15,20	2352	2087	120445
Heat-treated	0.017x0.025	30,40,50	2330	1918	113529
Heat-treated	0.017x0.025	60,75,90	2482	1758	108847
As-received*	0.018x0.025		2371	1602	104400
Heat-treated	0.018x0.025	10,15,20	2297	1982	117763
Heat-treated	0.018x0.025	30,40,50	2234	1839	110142
Heat-treated	0.018x0.025	60,75,90	2302	1685	107950

*Mean value for two specimens of as-received wires.

Mean value for six specimens of heat-treated wires.

As shown in Table 6, the modulus of elasticity after heat treatment generally increased by approximately 10% or less. The values of yield strength were again increased approximately 5% to 20%.

The mechanical properties of orthodontic wires are also determined under bending conditions because this mode of deformation is considered more representative of clinical use than the conventional test.

Values of springback, stiffness and modulus of resilience in bending for as-received and heat-treated wires are given in Table 7 for comparison.

Table 7 Comparison of yield strength, modulus of elasticity, springback, stiffness and modulus of resilience obtained in bending tests for as-received and heat-treated wires.

Bending Test							
Wire Type	Diameter (inch)	Time (second)	YS (MPa)	Modulus (MPa)	Springback	Stiffness	Resilience (MPa)
As-received*	0.014		2628	161899	0.016	62.5	21.3
Heat-treated	0.014	10,15,20	3119	168699	0.018	55.6	28.8
Heat-treated	0.014	30,40,50	2851	172108	0.016	62.5	23.5
Heat-treated	0.014	60,75,90	2686	176794	0.015	66.7	20.4
As-received*	0.016		2778	140057	0.02	50	27.6
Heat-treated	0.016	10,15,20	3320	144259	0.023	43.5	38.2
Heat-treated	0.016	30,40,50	3300	144679	0.023	43.5	37.6
Heat-treated	0.016	60,75,90	3025	148460	0.02	50	30.8
As-received*	0.018		2682	146454	0.018	55.6	24.6
Heat-treated	0.018	10,15,20	3205	153777	0.021	47.6	33.4
Heat-treated	0.018	30,40,50	3189	153337	0.021	47.6	33.2
Heat-treated	0.018	60,75,90	3074	153484	0.02	50	30.8
As-received*	0.016x0.022		2528	132247	0.019	52.6	24.2
Heat-treated	0.016x0.022	10,15,20	3001	137272	0.022	45.5	32.8
Heat-treated	0.016x0.022	30,40,50	3015	136479	0.022	45.5	33.3
Heat-treated	0.016x0.022	60,75,90	2857	137801	0.021	47.6	29.6
As-received*	0.017x0.025		2313	133576	0.017	58.8	20
Heat-treated	0.017x0.025	10,15,20	2727	139053	0.02	50	26.7
Heat-treated	0.017x0.025	30,40,50	2759	145464	0.019	52.6	26.2
Heat-treated	0.017x0.025	60,75,90	2720	145598	0.019	52.6	25.4
As-received*	0.018x0.025		2136	120495	0.018	55.6	18.9
Heat-treated	0.018x0.025	10,15,20	2499	123628	0.02	50	25.3
Heat-treated	0.018x0.025	30,40,50	2521	124833	0.02	50	25.5
Heat-treated	0.018x0.025	60,75,90	2407	130756	0.018	55.6	22.2

*Mean value for two specimens of as-received wires.
Mean value for six specimens of heat-treated wires.

Except for 0.014, 0.016, 0.018 and 0.018x 0.025-inch diameter at 60,75 and 90 seconds, the mean values of springback for all wires were higher in heat-treated wires than as-received wires. As shown in Table 7, the stiffness after heat treatment increased approximately 0% to 18%. The values of modulus of resilience in heat-treated wires were again higher than as-received wires for all heat-treated wire groups by approximately 4% to 37%, whereas the modulus of resilience of the 0.014-inch diameter wires at 60,75 and 90 seconds is decrease by 0.5%.

The results of an application test are summarized in Table 8.

Table 8 Comparison of the distance before and after stretching for the as-received wires and after 20 seconds heat-treated wires at 4 Newton loading.

NO.	WIRE SIZE											
	0.014”						0.016”					
	As-Received			Heat-treated			As-Received			Heat-treated		
	Do	D_1	ΔD	Do	D_1	ΔD	Do	D_1	ΔD	Do	D_1	ΔD
1	8.3	9	-0.7	8.2	6.9	1.3	8.3	9.5	-1.2	8.0	7.1	0.9
2	8.2	9.6	-1.4	8.2	7.2	1	8.3	9	-0.7	8.3	7	1.3
3	8.3	9.5	-1.2	8.3	7	1.3	8.2	9.2	-1	8.2	7.3	0.9
4	8.3	9.2	-0.9	8.1	7.1	1	8.2	9.4	-1.2	8.2	7.4	0.8
5	8.1	9.1	-1.0	8.3	7.3	1	8.1	9.6	-1.5	8.1	7.1	1
6	8.3	9.7	-1.4	8.3	7.2	1.1	8.3	9	-0.7	8.3	7.2	1.1
7	8.2	9.6	-1.4	8.3	6.9	1.4	8.1	9.1	-1	8.1	6.8	1.3
8	8.2	9	-0.8	8.1	7.1	1	8.3	9.7	-1.4	8.3	7.3	1
9	8.3	9.5	-1.2	8.2	7.3	0.9	8.2	9.2	-1	8.3	7	1.3
10	8.1	9.6	-1.5	8.3	7	1.3	8.3	9.3	-1	8.3	7.2	1.1
Average	8.23	9.38	-1.15	8.23	7.1	1.13	8.23	9.3	-1.07	8.21	7.1	1.11

D_0 = Chord (Arch width) of an archwire before stretching.

D_1 = Chord (Arch width) of the same archwire after stretching.

$\Delta D = D_0 - D_1$

Positive ΔD indicates an increase in springback.

Negative ΔD indicates a decrease in springback.

Table 8 Comparison of the distance before and after stretching for the as-received wires and after 20 seconds heat-treated wires at 4 Newton loading. (Continued)

NO.	WIRE SIZE											
	0.018”						0.018 x 0.025”					
	As- Received			Heat-treated			As- Received			Heat- treated		
	Do	D_1	ΔD	Do	D_1	ΔD	Do	D_1	ΔD	Do	D_1	ΔD
1	8.2	9.2	-1	8.3	6.8	1.5	8.3	9	-0.7	8.1	7.4	0.7
2	8.3	9.4	-1.1	8.1	7.1	1	8.3	8.9	-0.6	8.3	7.1	1.2
3	8.3	9.5	-1.1	8.3	7.3	1	8.3	8.8	-0.5	8.2	7.3	0.9
4	8.3	9.1	-0.8	8.3	7	1.3	8.0	9.1	-1.1	8.3	7	1.3
5	8.1	9.7	-1.6	8.2	7.4	0.8	8.3	8.9	-0.6	8.3	7.5	0.8
6	8.2	9.5	-1.3	8.1	6.9	1.2	8.3	9	-0.7	8.2	7.2	1
7	8.2	9	-0.8	8.1	7.2	0.9	8.2	9.2	-1	8.1	7.6	0.5
8	8.3	9.6	-1.3	8.3	7.1	1.2	8.3	9.3	-1	8.1	7.4	0.7
9	8.0	9.2	-1.2	8.2	7.3	0.9	8.3	9	-0.7	8.2	7.5	0.7
10	8.3	9	-0.7	8.3	7.5	0.8	8.3	8.8	-0.5	8.3	7.3	1
Average	8.22	9.3	-1.08	8.22	7.2	1.02	8.26	9	-0.74	8.21	7.3	0.91

D_0 = Chord (Arch width) of an archwire before stretching.

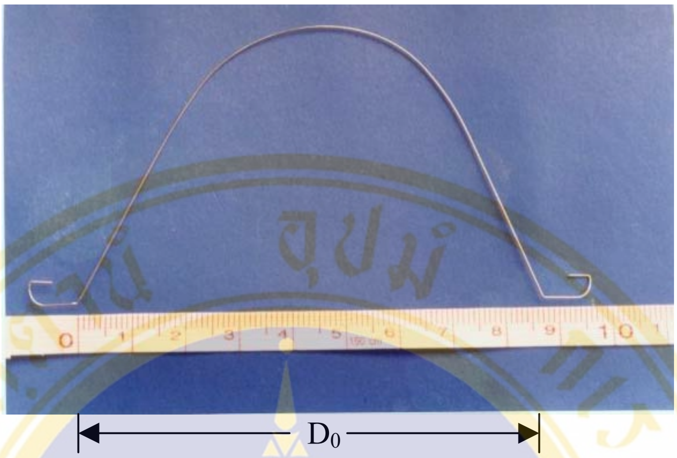
D_1 = Chord (Arch width) of the same archwire after stretching.

$\Delta D = D_0 - D_1$

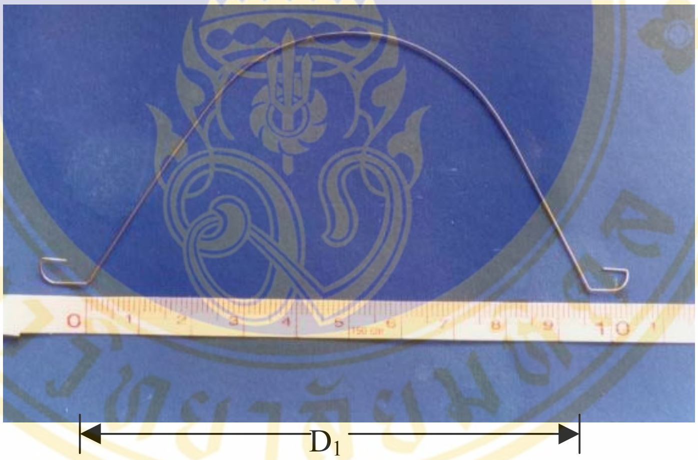
Positive ΔD indicates an increase in springback.

Negative ΔD indicates a decrease in springback.

As shown in Table 8, the chord of as-received wires was generally increased after the release of stretching force by approximately 14%. Except for 0.018”x0.025” diameter, the mean values of ΔD is approximately -8.9%. In general statement, non-heated wires have their springback decrease after stretching, as shown typically in Figure 21. Whereas for heat-treated wires, the chord was generally decreased after stretching by 11%-13%, indicating an increase of springback, as shown in Figure 22.

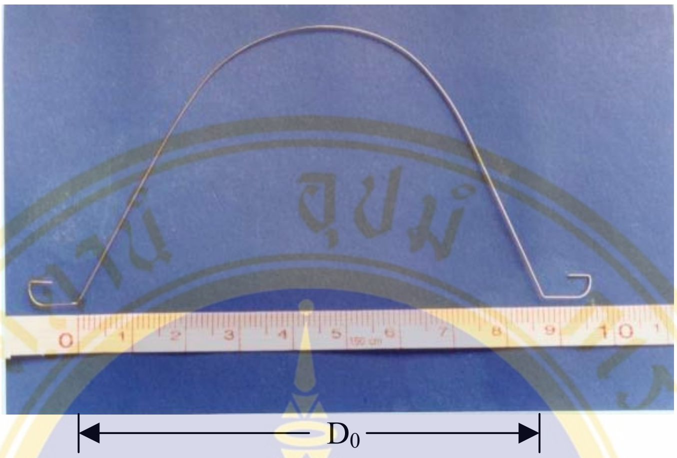


As-received wire before stretching.



As-received wire after stercthing.

Figure 21 Shows a decrease in springback of an as-received wire after stretching.



Heat-treated wire before stretching.

Heat-treated wire after stretching.

Figure 22 Shows an increase in springback of heat-treated wire after stretching. ($D_1 < D_0$)

The above application test results in table 8 confirm the bending test results shown in table 7.

The overall test results show that the constructed OWHT Apparatus can heat-treat the orthodontic wires to improve their strength, modulus of elasticity, springback, stiffness and modulus of resilience quite noticeably.

CHAPTER VI
DISCUSSIONS OF RESULTS

The results show that the most increases in the modulus of elasticity can be obtained by suitable low temperature heat treatment of as-received wires, and were found to increase approximately 10% or less (Table 7). The effect of heat treatment on yield strength for orthodontic wires dramatically increases, generally, with percentage from 5% to 20%. From Table 7, the values of the modulus of resilience are acceptable, due to the values of yield strength are larger than the modulus of elasticity occurs from the heat treatment.

The improvement in the mechanical properties of modulus of elasticity and yield strength for orthodontic wires following heat treatment ensures greater modulus of resilience and increases resistance to permanent deformation. The accompanying internal stress relief reduces the likelihood for premature fracture during clinical manipulation.

The properly heated wires are relatively ductile and more resilient than as-received wires. They can also be bent with relative ease.

The wires heated for 60,75 and 90 seconds have a smaller springback than the wires of comparable sizes heated for 10,15,20,30,40 and 50 second. This implies that lower amounts of heat produce orthodontic wires with better springback making them more suitable to dental works by their ability to last longer. This property, however, can be improved by a proper choice of time for heat treatment. The ideal time for heat treatment is for 10 to 20 seconds by the OWHT Apparatus so constructed. Heat treatment above 60 seconds results in a rapid decline in resistance due to a change in mechanical property.

The measured values of yield strength and modulus of elasticity generally were also significantly higher in bending than in tension. These differences occur because the onset of permanent tensile deformation takes place uniformly over the entire cross section, but begins only at the outermost portion for bending.

From the results in chapter V, the optimal time for heat treatment are in the range between 10 to 50 seconds for relatively constant mechanical properties obtainable from tension and bending tests. If the wires are heat-treated too long, the mechanical properties noticeably decreased as shown by the results in the range of 60 to 90 seconds.

The variation for tension and bending mechanical properties in each wire size may be associated with human and mechanical error. Generally, human error occurs in every kind of measurement system because each operator processes different measurement techniques and skills. Thus, the variation also occurs in different measurement by the same operator.

In this study, human error eventhough largely overcome by an orthodontic feature of the OWHT apparatus, can also occurred because the system requires a certain degree of technical handling. However, the results of repetitive tests and measurements have confirmed the reliability of the apparatus so constructed and operated.

It must be stated here that the testing machine in use is satisfactory only for testing large diameter wires, thus we must be aware of the results of tests on orthodontic wires which are fairly small for the machine. Therefore, several tests under the same condition are needed for each wire size in the same condition to produce a needed high precision.

The results of the prototype apparatus testing in actual scenario are assessed by an orthodontist* of Mahidol University on the subjective basis for acceptability of the apparatus as a good prototype for some further developments into an acceptable piece of medical equipment in orthodontic works. The orthodontist's remarks are summarized in Table 9 below.

Table 9 The orthodontist's suggestions for the prototype apparatus.

Physical Observation	Acceptability for usage	Remarks
Time setting	Good	
Time control	Good	
Wire size selection knob	Good	
Orthodontic wire terminal or clamp	Fair	Should be adjustable to arch width.
Heat-treated wires	Good	
Weight	Good	
Design	Too bulky	
Other		Should be has Foot switch option

* Dr. N. Anuwongnukroh

CHAPTER VII
CONCLUSION

The main objective of this thesis is to design and build an orthodontic wire heat treatment apparatus through which the required current can be set by selecting the time required by the size of stainless steel wires. The wire can be heated only for an amount of time as set to the apparatus. Should the optimum time for heat treatment be known, the apparatus can be set to perform the required heat treatment automatically, to improve the mechanical properties of orthodontic wire to suit a desired dental work.

The benefits expectable from the use of this OWHT Apparatus are:

- Low stiffness provides the ability to apply little force, a more constant force over time as the orthodontic wire experiences deactivation.
- High springback values provides the ability to apply large activations, thus, increasing the working time of the orthodontic wire. Moreover, high springback allows a greater deflection of the wire without causing a permanent deformation to it.
- High modulus of resilience values provides the capability of an orthodontic wire to better rearrange the teeth.
- High formability provides the ability to bend a wire into a desired configuration without fracturing the wire.

Many investigators favor the use of bending tests for evaluation of orthodontic wires because this loading mode corresponds well to clinical conditions.

The orthodontic wire heat treatment apparatus so designed, constructed and tested can be regarded as satisfactory regarding its design concept, meeting principal requirements for orthodontic works. The apparatus should be subjected to a further study and mechanical tests of the heat-treated wires should be performed with a more suitable testing machine to better differentiate the results for reliable comparison with the performances in actual scenario.

REFERANCES

1. E.C. Combe. Note on dental materials. 6th ed. London: Churchill Livingstone; 1992.
2. William R. Proffit, Henry W. Fields, Jr., James L. Ackerman, L'Tanya J. Bailey, J.F. Camilla Tulloch. Contemporary Orthodontics. 3rd ed. New York: Mosby; 2000.
3. J.F. McCabe, A.W.G. Walls. Applied dental materials. 8th ed. Blackwell Science; 1998.
4. Bernard G.N. Smith, Paul S. Wright, David Brown. The clinical Handling of dental materials. 2nd ed. Oxford: Wright; 1998.
5. William J. O'Brien. Dental materials: Properties and selection. Chicago: Quintessence Publishing Co., Inc; 1989.
6. Sunai Kapila, Rohit Sachdeva. Mechanical properties and clinical applications of orthodontic wires. Am.J. Orthod. Dentofacial 1989; 96(2): 100-109.
7. Jack L. Ferracane. Materials in dentistry: Principles and Applications. Philadelphia: J.B. Lippincott Company; 1995.
8. J.K. Williams, P.A. Cook, K.G. Isaacson, A.R. Thom. Fixed Orthodontic appliances. Wrighr;1995.
9. Robert G. Craig. Restorative dental materials. 7th ed. St Louis: The C.V. Mosby Company;1985.
10. W.J. B. Houston. Walther's Orthodontic notes. 4th ed. Bristol: Wright: PSG; 1983.
11. Daniel W. Hart. Introduction to power electronics. New Jersey: Prentice Hall; 1997.
12. Adel S. Sedra, Kenneth C. Smith. Microelectronic circuits. 3rd ed. New York: Oxford University Press; 1997.

13. A. James Diefenderfer, Brian E. Holton. Principles of electronic instrumentation. 3rd ed. Philadelphia: Saunders college publishing; 1993.

14. Paul Watkin. Switching VS. Linear power supplies. British Columbia: ICT;1997 http://iwce-mrt.com/ar/radio_switching_vs_linear/

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