6-1981

Time vs. Force Relaxation in Utility Arches

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TIME VS. FORCE RELAXATION IN UTILITY ARCHES

by

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A Thesis in Partial Fulfillment
of the Requirements for the Degree
of Master of Science in the Field of Orthodontics

June 1981

Each person whose signature appears below certifies that this thesis in his/her opinion is adequate, in scope and quality, as a thesis for the degree of Master of Science.

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CONTENTS

TABLES

FIGURES

TIME VS. FORCE RELAXATION IN UTILITY ARCHES

CHAPTER I

INTRODUCTION

Clinical observations show that orthodontic wires frequently lose part of their activation after a period of time. Much or all of the activation in a frictionless cuspid retractor or intruding utility arch diminishes after three or four weeks, yet the tooth movement observed may not be sufficient to account for the loss of activation. The following questions come to mind: Was the activation lost upon tying the appliance in the mouth? Did the oral environment initiate the loss of force, or did the wire simply weaken after a period of time? Did the loss of activation occur due to some single incident; was it a gradual process, or a combination of the two? How much of the force loss realized was due to intrinsic deficiencies in the wire itself, and how much was dependent on extrinsic factors?

A search of the literature on this topic yielded only Lacey's 1980 thesis,[1] which evaluated different devices used to measure light forces such as those used in orthodontics. He found no satisfactory means of evaluating force losses in wire, and then developed a means of measuring and recording forces over a long period of time utilizing electronic load cells. By recording those forces at different time intervals, he was able to obtain a curve for the rate of force decay in a given system.

This study enlarged on Lacey's work and was designed to test the amount of force, applied by several types (determined by composition and heat-treatment condition) of orthodontic wires, that was lost over a period of time when negligible movement was realized.

CHAPTER II

MATERIALS

Selection of Wires

The wires tested in this project were selected on the basis of clinical use by the faculty and graduate students at Loma Linda University, School of Dentistry, Department of Orthodontics. Wires clinically used for similar types of activation were tested and compared with each other. Blue Elgiloy, Permachrome Standard, and Multiphase were chosen as wires most commonly used for orthodontic forces such as intrusion, extrusion, tipping, torquing, and rotating. The .016 X .016 inch size was chosen for all categories of wire.

Much of the literature[2,3,4,5] supports the stress-relieving effect of heat treatment on certain wires. Therefore, the experimental wires were tested in both heat-treated and non-heat-treated states.

The shape and length of the wires were based on commonly used shapes and spans in bioprogressive mechanics. The shape decided upon was representative of the anterior and posterior vertical steps and the buccal bridge of a utility arch (Fig. 1). The length chosen was 31 mm, an average clinical length.[6]

Selection of Apparatus

The basic apparatus (Fig. 2) for this project was reported by Lacey,[1] and consists of a constant power supply, A; an

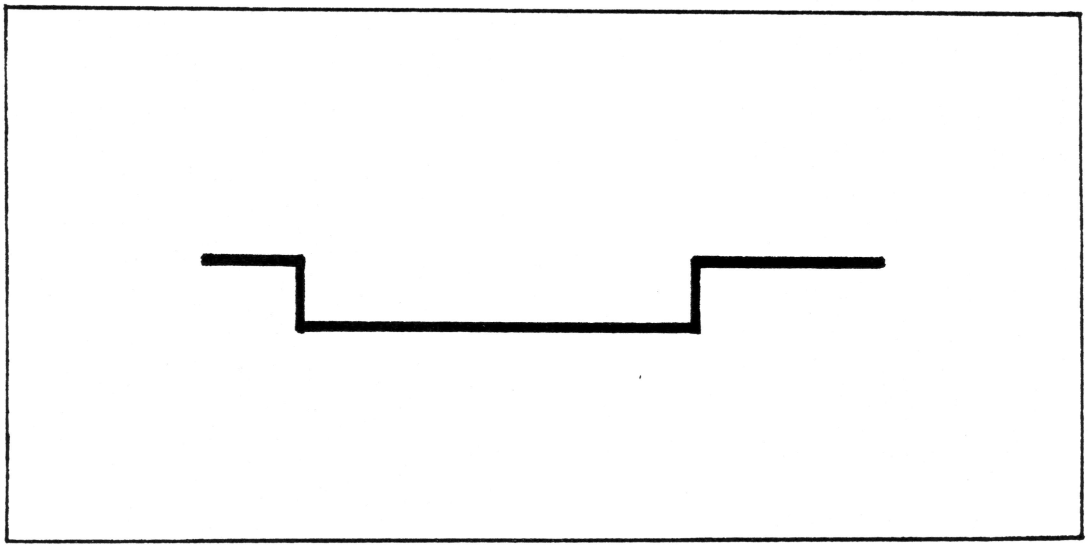

Figure 1. Diagram of Sample Wire

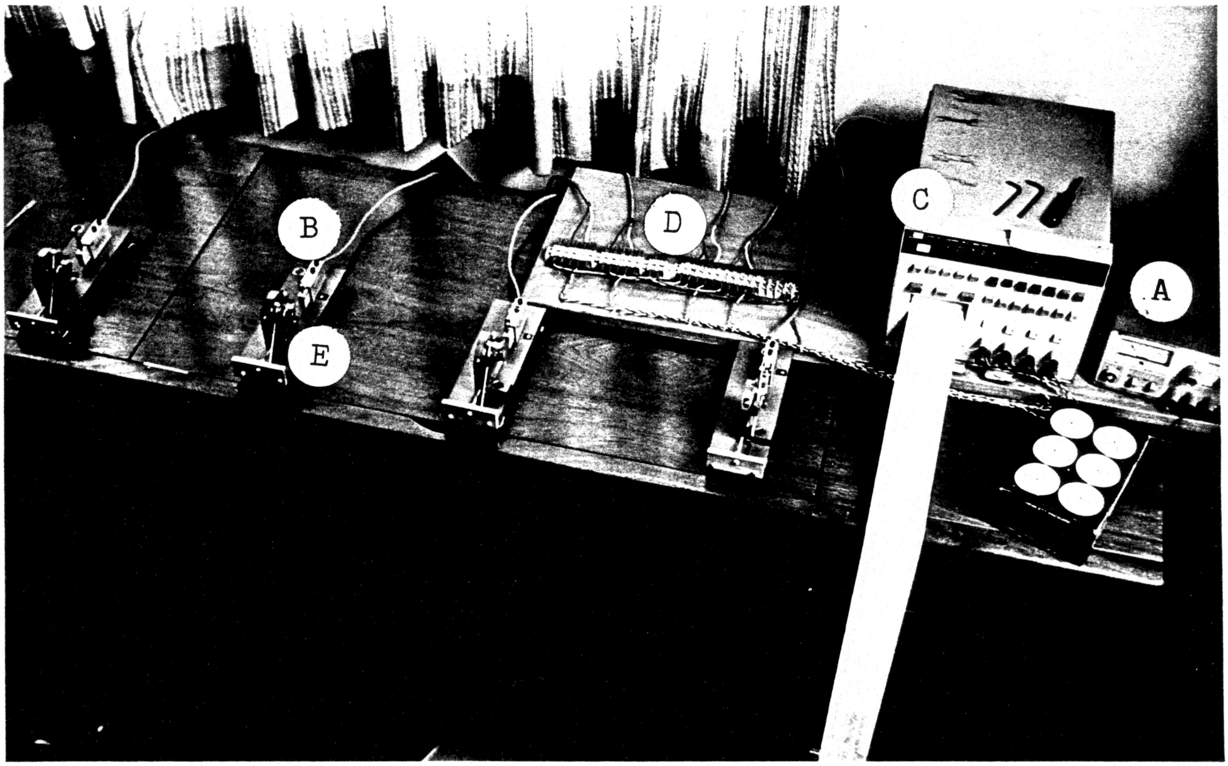

Figure 2. Photograph of Apparatus

electrical load cell, B; an electronic logging multimeter, C; miscellaneous electric materials, D; and a mounting device, E.

Hewlett-Packard, Model 6234A, (Fig. 3) was the power supply unit used to provide the load cells with the required D.C. power.[7] The 6234A stepped down and regulated the variable voltage from the 110 volt wall outlet to insure that the power to the load cells remained constant at all times, eliminating erroneous readings due to fluctuations in power.

Figure 3. Photograph of the Power Supply, Hewlett-Packard, Model 6234A.

From the constant power supply the current is passed to the load cell (Fig. 4). The load cells, Model K2's, manufactured by Western Load Cell Company,[8] are rated for a maximum load of five pounds. The load cell takes the input voltage and, with negligible movement, changes it in proportion to the force exerted against the cell to produce an output voltage, which can be interpreted as a unit of weight or force.

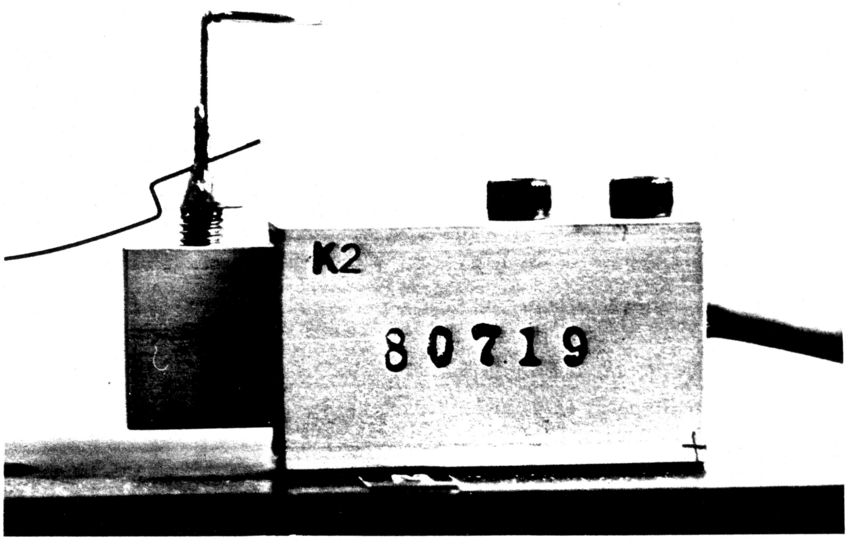

Figure 4. Photograph of a Load Cell, Western Load Cell Company, Model K2.

The output from the load cell is then directed to the Hewlett-Packard Model 3467A logging multimeter (Fig. 5),[9] which has an internal power supply to protect from voltage fluctuation. The capability of the 3467A to record and refer to the initial incoming voltage makes it possible to zero the instrument at virtually any voltage. This initial voltage becomes zero, and the voltage differences from the initial give the readout. A digital display indicates the change in millivolts and gives an instant and continuously available reading of the forces produced. It can be selected to scan all readings, any specific reading, or any combination of the readings at any time.

A built-in timer allows for a reading to be taken at practically any time the operator desires. The instrument is

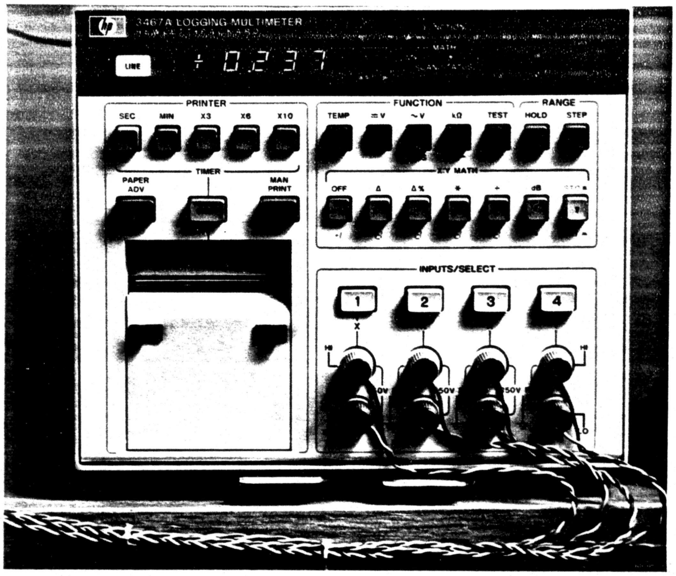

Figure 5. Photograph of the Logging Multimeter, Hewlett-Packard, Model 3467A.

programed when to record the data, and at the appropriate time produces a thermal paper printout with the time and data recorded. This printout is repeated at the indicated interval, making multiple readings in passage of time possible without interference to the apparatus. The additional function of reading multiple tests at the same time allows tests to be run on four load cells and recorded simultaneously.

A device to hold the wire and the load cell in a constant relationship (Fig. 6) was designed by Lacey. This device was slightly modified to increase fine tuning adjustability and accuracy. Two of the modifications were incorporated to give the device a horizontal and vertical adjustment (Fig. 7). A screw-type mechanism was used to control fine

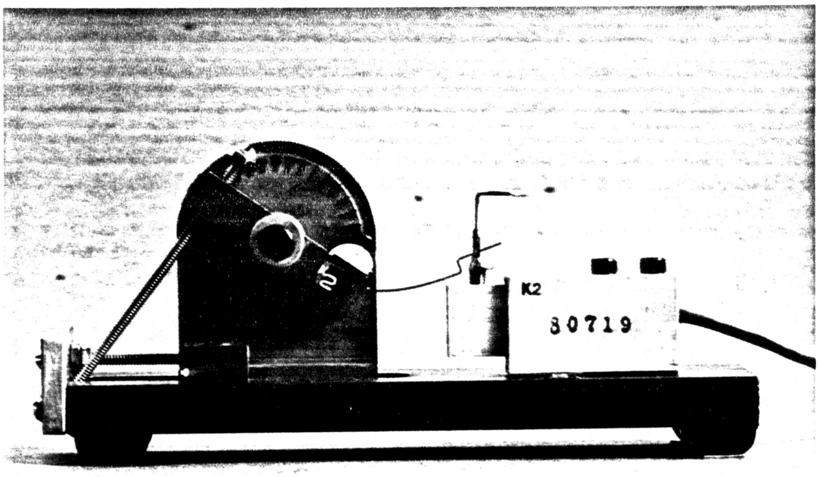

Figure 6. Photograph of the Holding Device with Load Cell and Activated Wire.

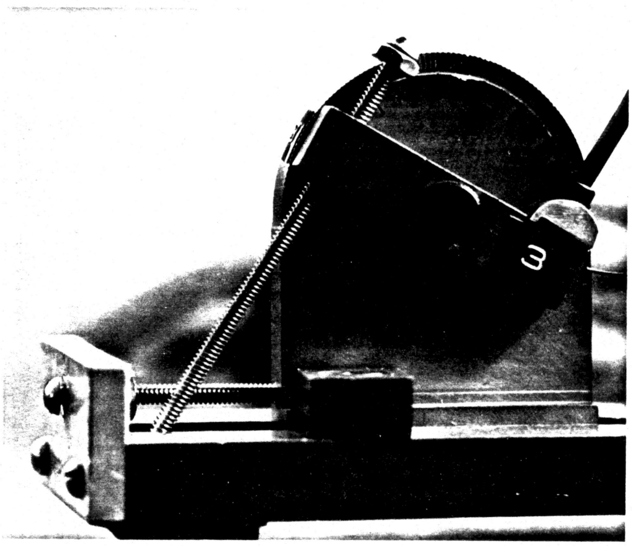

Figure 7. Photograph of Screw-type Mechanism Used to Control Fine Movements in Both the Vertical and Horizontal Directions.

movements in both directions. A third modification was made to eliminate the error introduced by indeterminable length variation due to the method by which the wire was held. A small metal lug (Fig. 8) was prepared to work as the movable jaw of a vise. The holding device arm was used as the immovable jaw, and the wire was pinched between them at a precise spot.

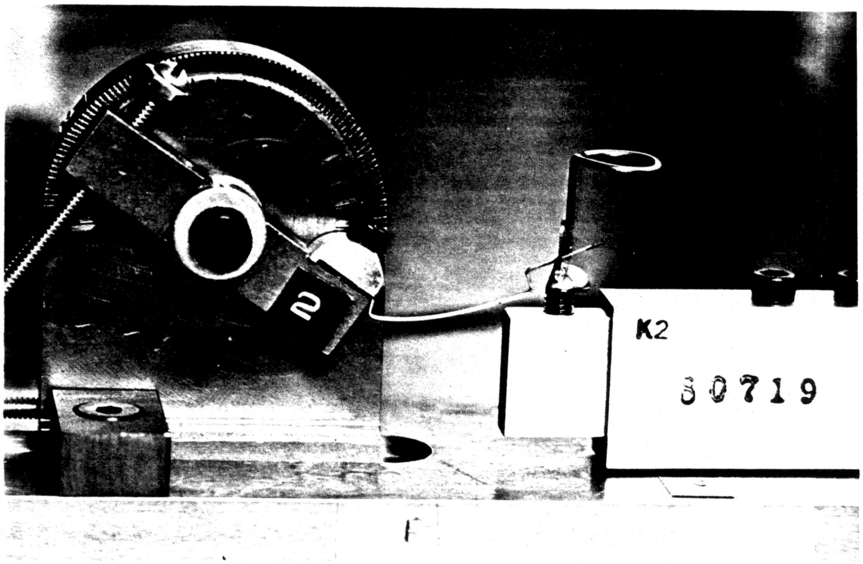

Figure 8. Photograph of Lug Vise Mechanism with Wire in Position.

The device was constructed in such a way so as to provide mounting of the load cell in a static position at one end, while at the other end, with both a vertical and horizontal adjustment, the test wire would be held firmly in position. The wire could then be moved by means of the horizontal and vertical screw adjustment to produce a predetermined amount of force on the load cell while maintaining a predetermined length of activated wire.

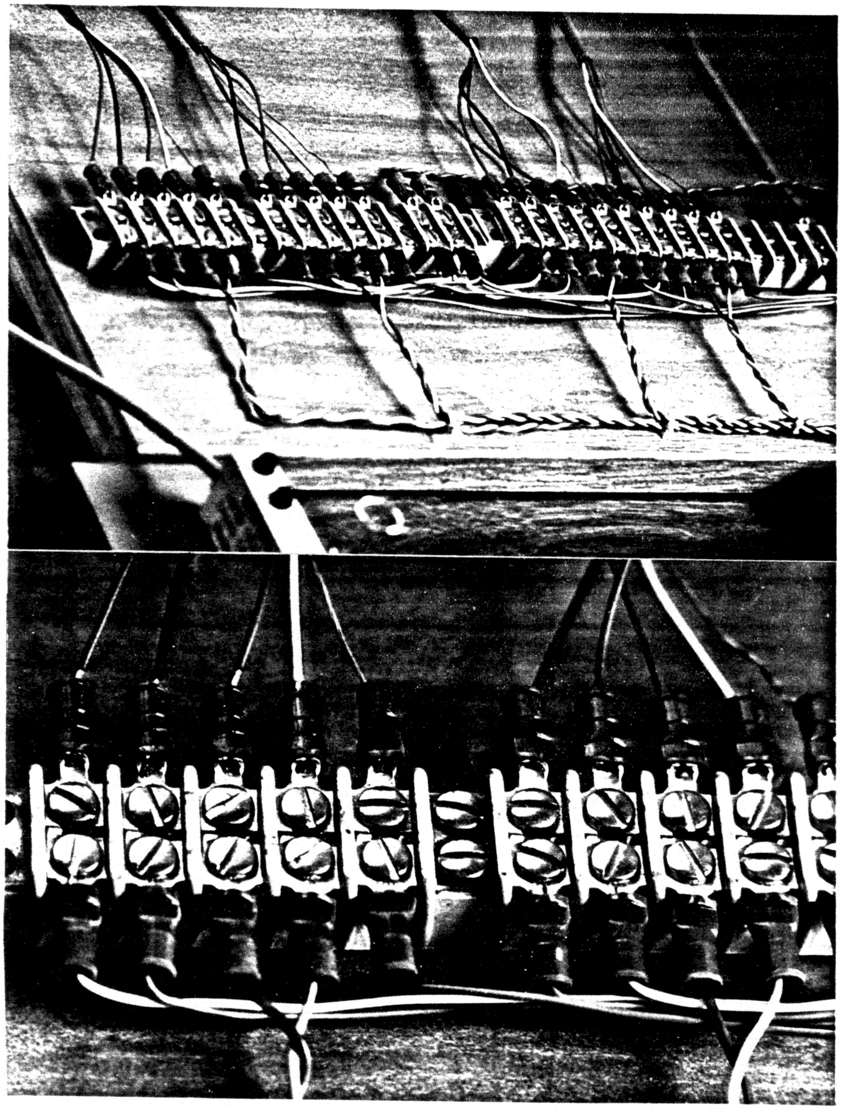

Figure 9. Photograph of Terminal Lugs and Barrier Strip

To insure continuity in the circuitry, the electronic devices were connected with wire, crimped terminal lugs, and a screw mount barrier strip (Fig. 9). This equipment was set up and tested by an electronic engineer.[10] All the apparatus was firmly attached to the counter top to eliminate movement that could strain connections and/or interfere with the measurements and data collection.

CHAPTER III

METHOD

Validity Testing of Apparatus

To establish the accuracy and validity of the testing equipment, the following procedure was performed. After the equipment was allowed to stabilize for 30 minutes (per manufacturer's instructions) and zeroed, four different standardized gram weights were placed, one on each of the four load cells, for a 24-hour period with recorded bi-hourly printouts. This was repeated 5 times, with similar data resulting.

A second procedure determined the long-term reliability of the equipment. A four-week extended trial of the first procedure with readings every three hours was performed. Again the readings of the constant weights were without significant change over the four-week period of time.

These tests showed that there was no significant difference in millivolts from T_1 to T_2 which is what was expected with a known constant weight on the load cell. The readings for each load cell were proportionately different for the different weights. The zeroed readings before and after were found to be within ± 0.004 mV, approximately 0.8 g. All this strongly indicates that the testing equipment was extremely accurate and possessed a high degree of stability, reliability, and validity for the experimental tests to be performed.

Wire/Load Cell Random Selection

The wire to be tested on a particular load cell at a particular time was determined by random selection. Symbols for the wires to be tested were placed in a box and taken out one at a time, and the corresponding wire sample was tested in that order if the following conditions were met: 1) only one wire of each type could be tested at a time 2) all wire types had to be tested once before any could be tested twice. The wires were selected in this way so that any uncontrollable disturbance that might cause erroneous readings would not be confined to one wire sample, but would be seen in the four wires being tested at the time of the disturbance. This eliminated the possibility of four test wires of the same type being affected in the same way, thereby introducing error into the data.

Preparation of Wire

The wire form, representative of one half of a utility arch (Fig. 1), traveled horizontally for approximately 6 mm, turned clockwise 90° and dropped 4 mm where it turned counter-clockwise 90° and extended horizontally 25 mm. At this point the wire again turned counter-clockwise 90° and traveled vertically 4 mm where it made a 90° clockwise bend and traveled 12 mm to terminate. This resulted in a total span of approximately 45 mm. All wires were bent at the same time around metal blocks held in a vise. This procedure assured that all wires were bent in as nearly the same shape and dimensions as possible.

A 31 mm section was involved in the test. The wire length from the jaws of the holding device to the contact point with the load cell was determined after the wire had been placed in the holding device. The vertical step of the wire was butted against the holding device, much as it would be against a molar tube, and the movable jaw adjusted to hold the wire securely in place (Fig. 10). Once the wire was accurately placed in the holding device, a metal template (Fig. 11) was used to mark the wire at the desired 31 mm length. This template was constructed with a notch located 31 mm from one edge (Fig. 11). The template was butted against the jaw of the holding device and the wire marked with a 0.2 mm line produced by a fine point felt pen at the template's edge (Fig. 11). This method insured accurate marking of the test wire length.

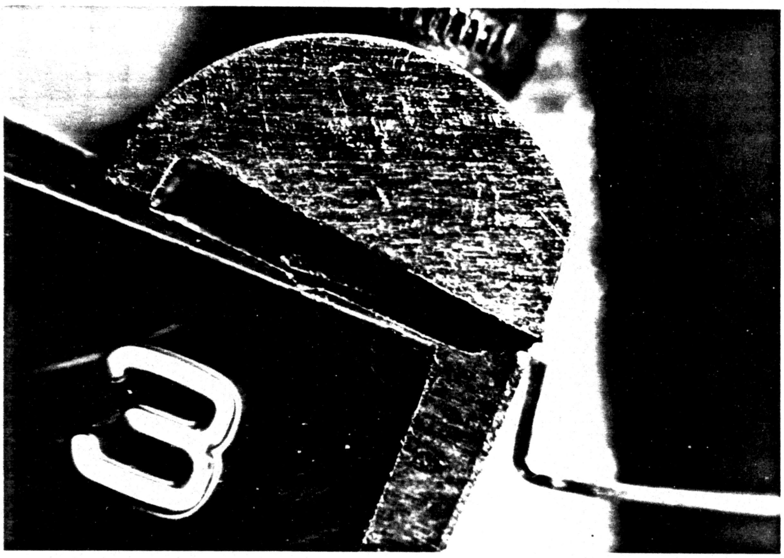

Figure 10. Photograph of Wire Set in Holding Device to Insure Equal Amounts of Wire in Each Test.

To determine the heat treatment procedure best suited for each particular type of wire, the literature[3,4] and distributers' specifications[11,12] were consulted. The procedure decided upon for Blue Elgiloy was an electronically controlled porcelain oven at 1200° F. for 5 minutes as described by Fillmore.[4] The procedure used for Permachrome Standard was an electronically controlled porcelain oven at 750° F. for 60 minutes as described by Dvivedi.[11] And the procedure used for Multiphase was an electronically controlled porcelain oven at 900° F. for 30 minutes as described by American Orthodontics.[12]

Preparation of the Apparatus

Just prior to running each test, the multimeter was zeroed and recorded ($zero_1$ reading); the gram weights were then placed on the load cells and the readings recorded (50 g weight reading). After this was done, the weights were removed and the $zero_2$ reading was taken.

Placement of Wire

The test wire was placed in the holding device and marked (Fig. 11). The holding device was then attached to the base with the loose end of the test wire inserted through the receiver slot of the load cell.

Activation of Wire

The test wire was then activated to produce a force on the load cell. As the vertical adjustment was used, the wire

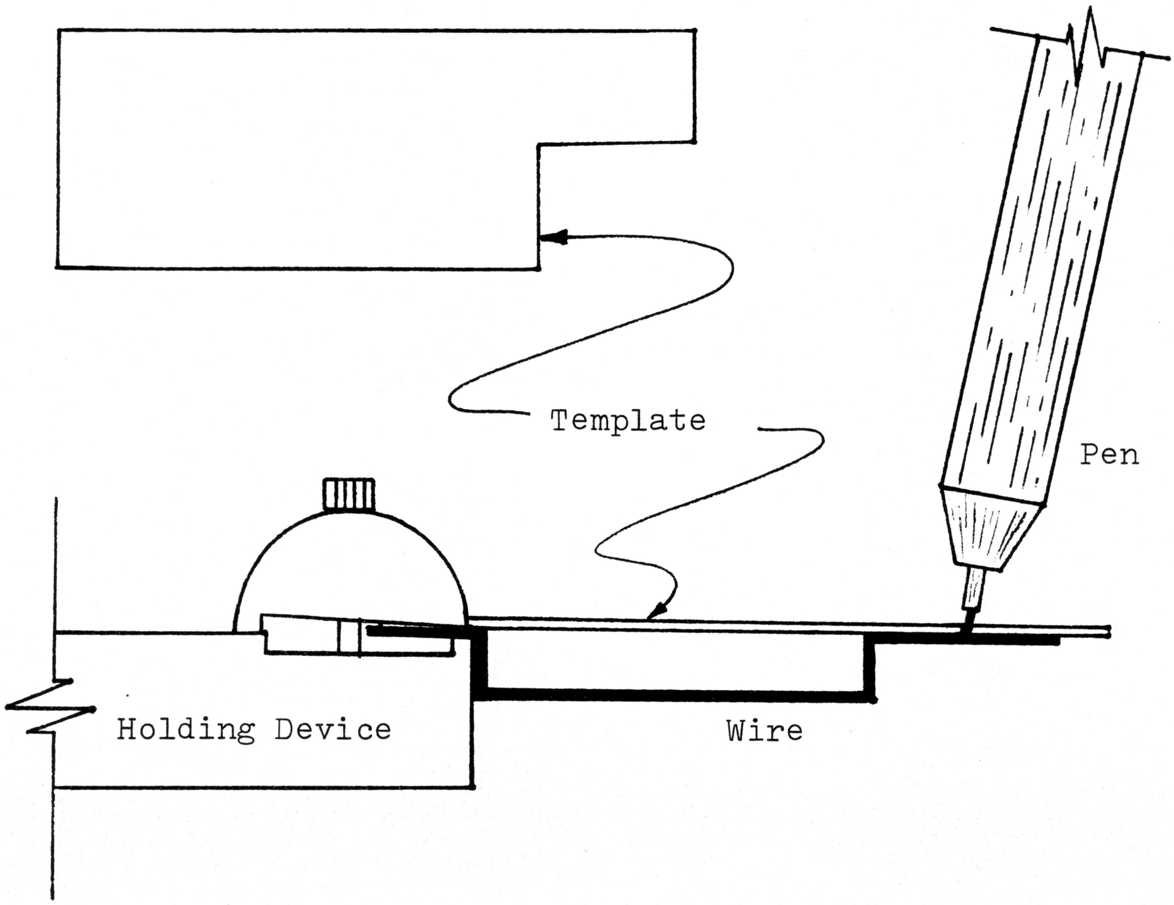

Figure 11. Test Wire Mounted in Holding Device with Template to Measure 31 mm Test Length. Pen Point in Position.

came in contact with the load cell and bent, thus producing a force against the load cell. As the wire bent, the space between the holding device and the point of contact with the load cell increased. This caused more wire to be involved in the activated section of the wire and, to compensate for this, the holding device was moved toward the load cell with the horizontal adjustment, thus maintaining the proper length of wire involved in the test. The horizontal and vertical positions were adjusted until the proper length of wire, as determined by the reference mark, was activated and the correct force applied to the load cell.

A force of 50 g was used to conform with Ricketts' technique.[6] This force was converted to millivolts for each of the four load cells with reference to the initial 50 g weight millivolt reading and was used to set the desired amount of force on the load cell.

Length of Trials

To determine the length of test to be used, reference was made to Lacey's[1] work which suggested two weeks as ample time to realize most of the force relaxation. However, the typical time between activations of appliances was three to four weeks. Taking this into consideration, the tests were initially run for three weeks. It was decided that if the initial data suggested that a shorter time period could be employed, the following criteria would have to be met: the change in a 24-hour period must be less than 1% of the total change from the initial time (T_1) to the end time (T_2).

As soon as the first wire was adjusted to the proper position and force, the T_1 reading was recorded. The readings were continued at 60 second intervals until the fourth wire had been activated for 10 minutes, at which time this sequence followed: a reading every 30 minutes for 2 hours, then every hour for 22 hours, and finally every 3 hours for the remainder of the test (Appendix A). All four wires were activated within the first five-minute period.

Apparatus Validity Check

After the test was completed, the forces produced by the wires were removed from the load cells and a $zero_3$ reading was taken. At this time known gram weights were placed on the cells, and another reading (50 g weight reading) was taken. The gram weights were then removed and a $zero_4$ reading taken (Appendix A). The equipment was then re-zeroed and the next set of trials begun, following the previous format.

This format gave baseline data before and after each trial, thus increasing the validity of the data collected and continually keeping the equipment's function under check. With this format a malfunction in the equipment would be detected and corrected before another trial was attempted.

CHAPTER IV

RESULTS AND DISCUSSION

A system was built into the study to eliminate error as quickly and effectively as possible. At the end of the first trial, the data looked consistant with the exception of load cell #1. Some secondary testing of the cells with equal standard weights was done at that time, and it was found that cell #1 had 25 times the standard deviation of cells #2, 3, and 4. It was, therefore, decided to eliminate cell #1 and continue the experiment with cells #2, 3, and 4. To minimize confusion the cells were renumbered 1, 2, and 3. Therefore, cell #2 became cell #1, and cell #3 became cell #2, and cell #4 became cell #3. The tables and charts in the body and appendix of the paper refer to the cells as #1, 2, and 3.

After the first trials, it was also apparent that virtually all the loss of force was occuring during the first 7 days (Appendix A, Tables I, II, III, and Figs. 12-15). The criteria for changing to a shorter trial period was met; and, therefore, the experiment continued using a seven-day format.

Tables I, II, and III show the means and standard deviation of force loss for the three trials on each wire in their heat-treated and non-heat-treated condition. These data were based on a one-week trial period. The first four and the last readings were overlapping and retroactive to the initial

TABLE I

BLUE ELGILOY--Mean Force Loss in Microvolts and Standard Deviations Over Indicated Time Period From Three Trials for Heat-Treated and Non-Heat-Treated Wires.

Time	Non-heat-Treated		Heat-Treated	
	Mean	Standard Deviation	Mean	Standard Deviation
*0-0.5 Hrs.	12	9.2	1	1.7
0-1	14	9.5	2	2.1
0-2	15	9.6	2	2.1
0-3	16	10.1	2	2.6
**3-6	1	0.0	1	0.6
6-12	1	1.2	0	0.6
12-24	1	0.6	0	0.6
***D2	2	1.7	0	0.0
D3	0	0.6	0	0.6
D4	0	0.6	0	0.6
D5	0	0.6	1	2.3
D6	1	0.6	0	0.0
D7	1	0.0	0	0.0
0-7 Days	24	10.4	5	5.0

*Lowest reading during indicated time period

**Average reading during indicated time period

***Average reading during day 2, etc.

1 g force loss = 5.4 microvolts

TABLE II

PERMACHROME STANDARD STAINLESS STEEL--Mean Force Loss in Microvolts and Standard Deviations Over Indicated Time Periods From Three Trials for Heat-Treated and Non-Heat-Treated Wires.

Time	Non-heat-Treated		Heat-Treated	
	Mean	Standard Deviation	Mean	Standard Deviation
*0-0.5 Hrs.	9	0.6	3	1.5
0-1	11	0.6	4	1.5
0-2	12	0.0	5	1.0
0-3	13	1.0	5	1.2
**3-6	1	0.6	1	1.0
6-12	1	1.0	1	1.5
12-24	1	1.5	1	1.2
***D2	0	0.0	0	0.0
D3	1	1.2	0	0.0
D4	0	0.6	0	0.6
D5	0	0.6	0	0.6
D6	0	0.0	0	0.6
D7	0	0.0	0	0.0
0-7 Days	17	2.3	9	5.8

*Lowest reading during indicated time period

**Average reading during indicated time period

***Average reading during day 2, etc.

1 g force loss = 5.4 microvolts

TABLE III

MULTIPHASE--Mean Force Loss in Microvolts and Standard Deviations Over Indicated Time Periods From Three Trials for Heat-Treated and Non-Heat-Treated Wires.

Time	Non-heat-Treated		Heat-Treated	
	Mean	Standard Deviation	Mean	Standard Deviation
*0-0.5 Hrs.	13	1.5	2	2.5
0-1	14	3.0	3	2.6
0-2	16	2.0	4	3.0
0-3	17	2.0	4	3.5
**3-6	2	1.0	1	1.0
6-12	1	1.2	1	0.6
12-24	2	2.6	1	1.2
***D2	1	0.6	0	0.0
D3	2	0.6	0	0.6
D4	2	1.0	1	1.2
D5	1	1.0	0	0.0
D6	0	0.6	0	0.0
D7 Days	0	0.6	0	0.0
0-7	29	2.0	8	4.9

*Lowest reading during indicated time period

**Average reading during indicated time period

***Average reading during day 2, etc.

1 g force loss = 5.4 microvolts

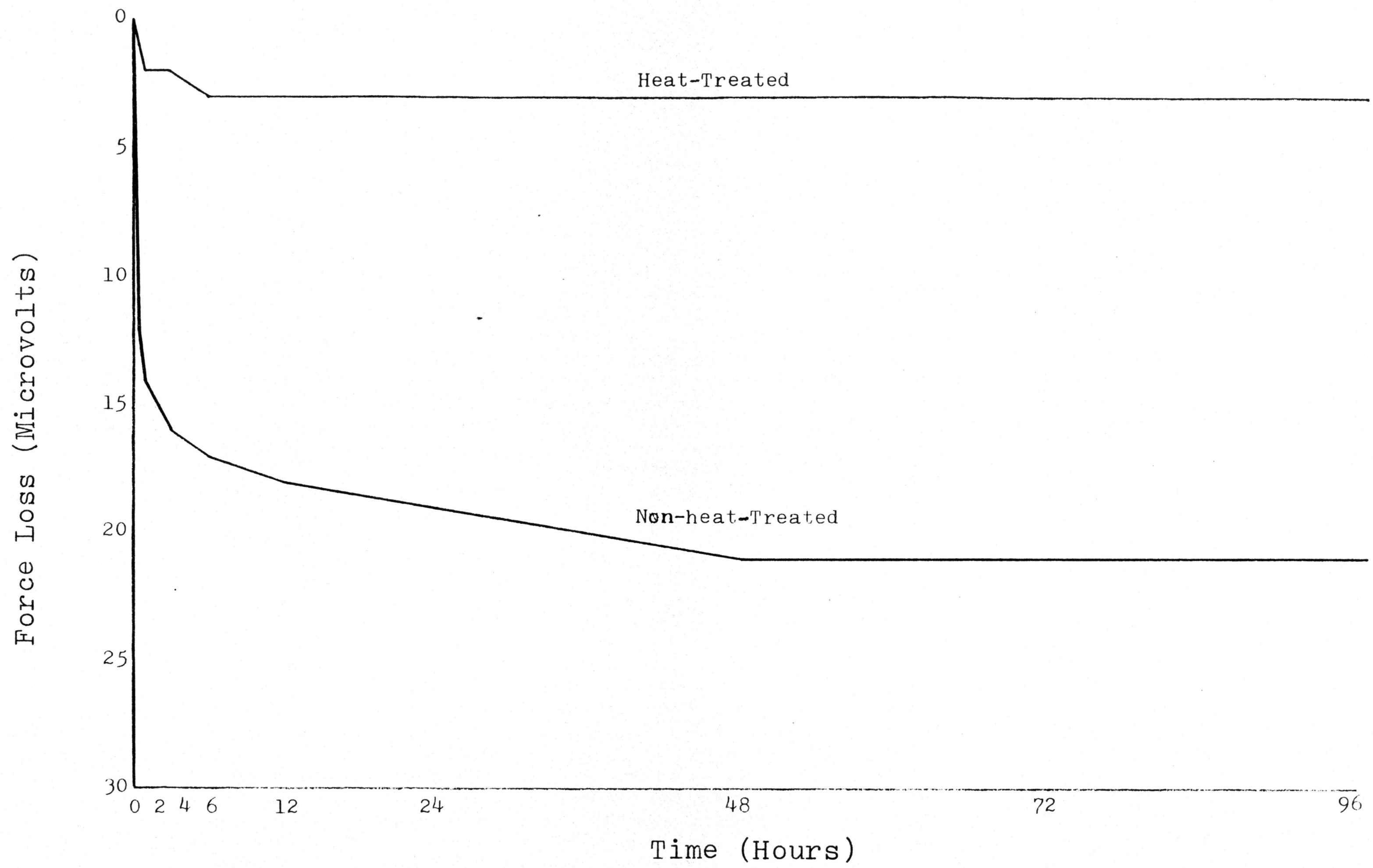

Figure 12. Force Loss Curve of BLUE ELGILOY in Heat-Treated and Non-Heat-Treated Condition.

1 g Force Loss = 5.4 Microvolts

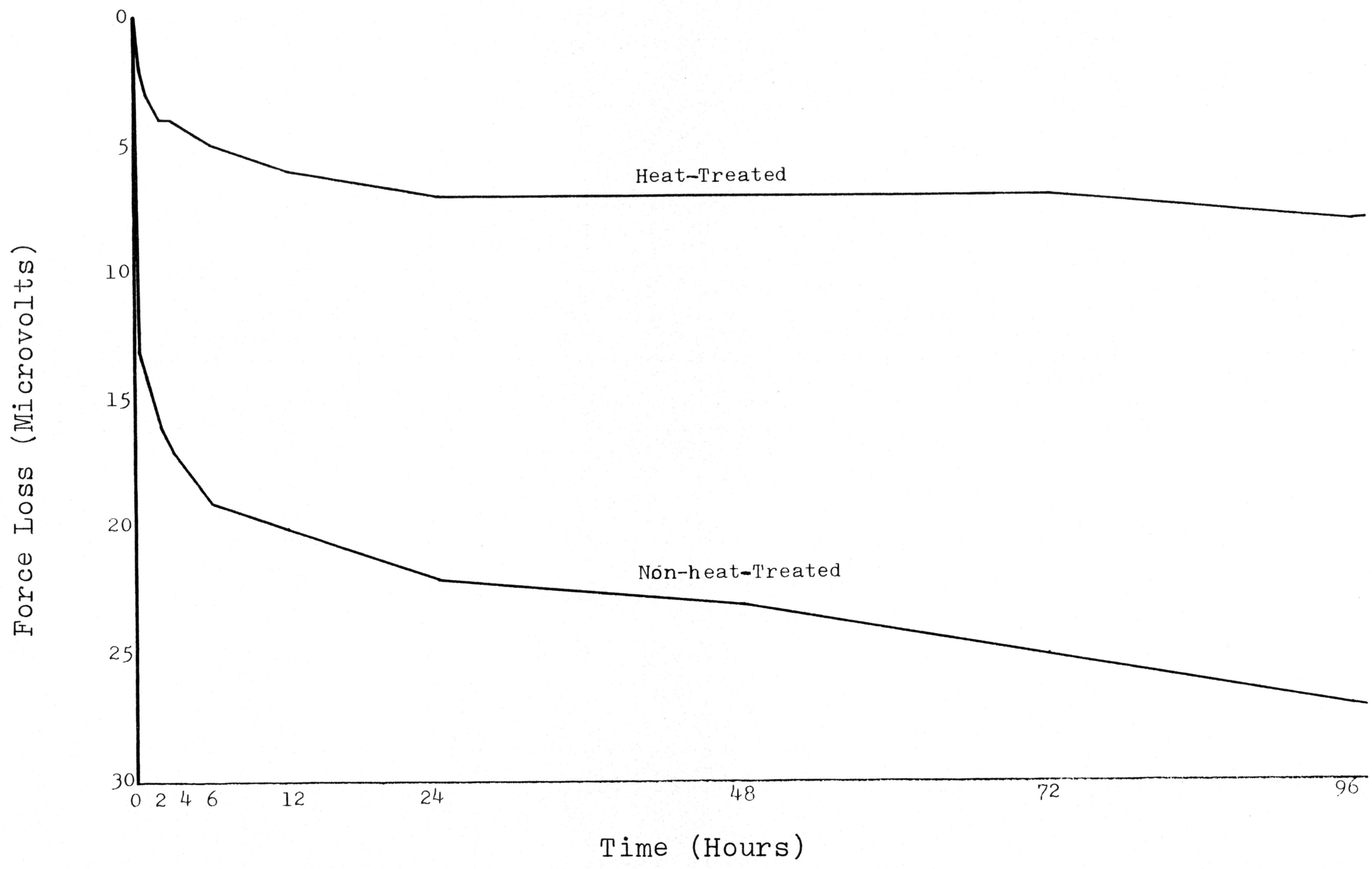

Figure 13. Force Loss Curve of <u>MULTIPHASE</u> in Heat-Treated and Non-Heat-Treated Condition.

1g Force Loss = 5.4 Microvolts

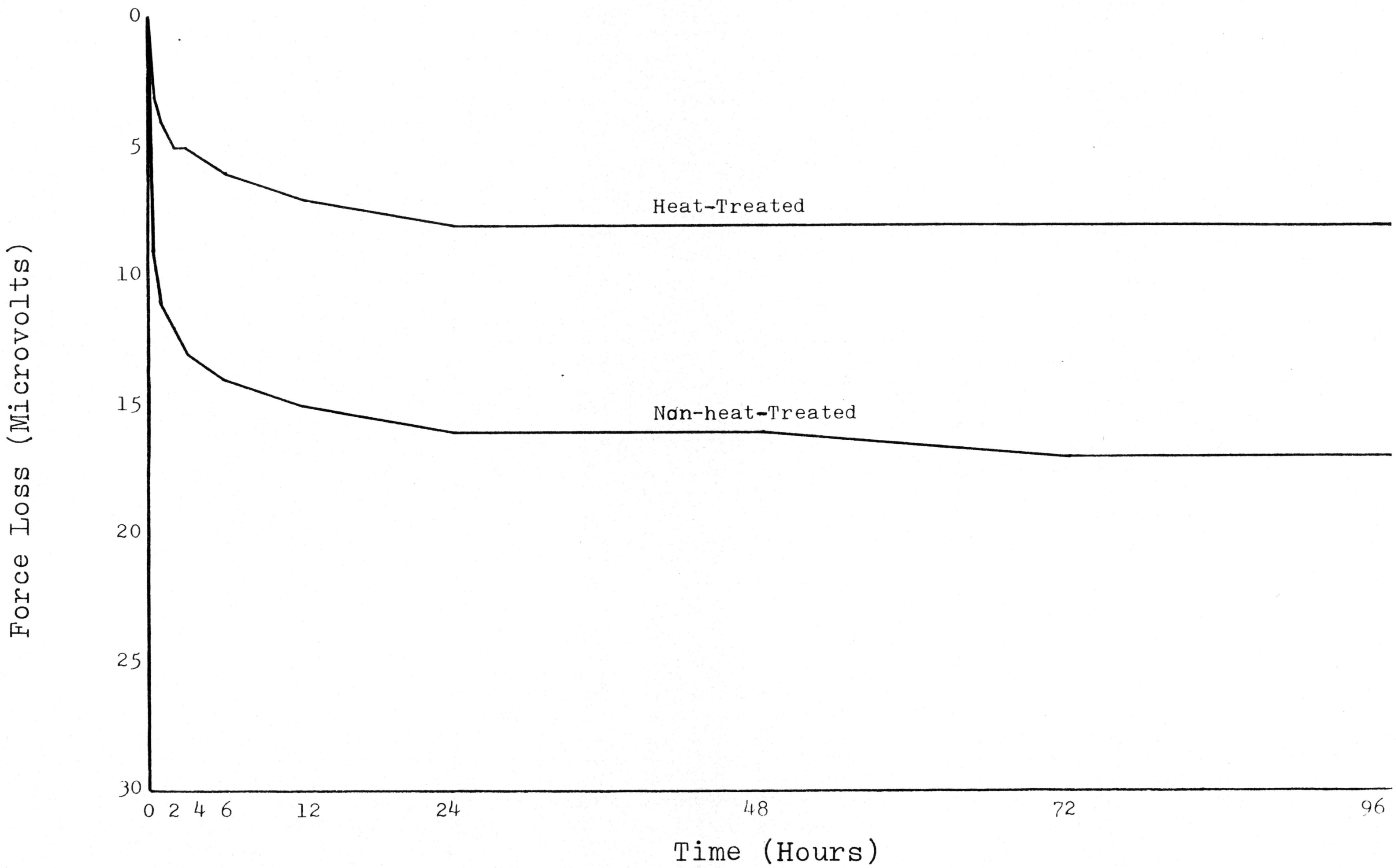

Figure 14. Force Loss Curve of PERMACHROME STANDARD STAINLESS STEEL in Heat-Treated and Non-Heat-Treated Condition.

1 g Force Loss = 5.4 Microvolts

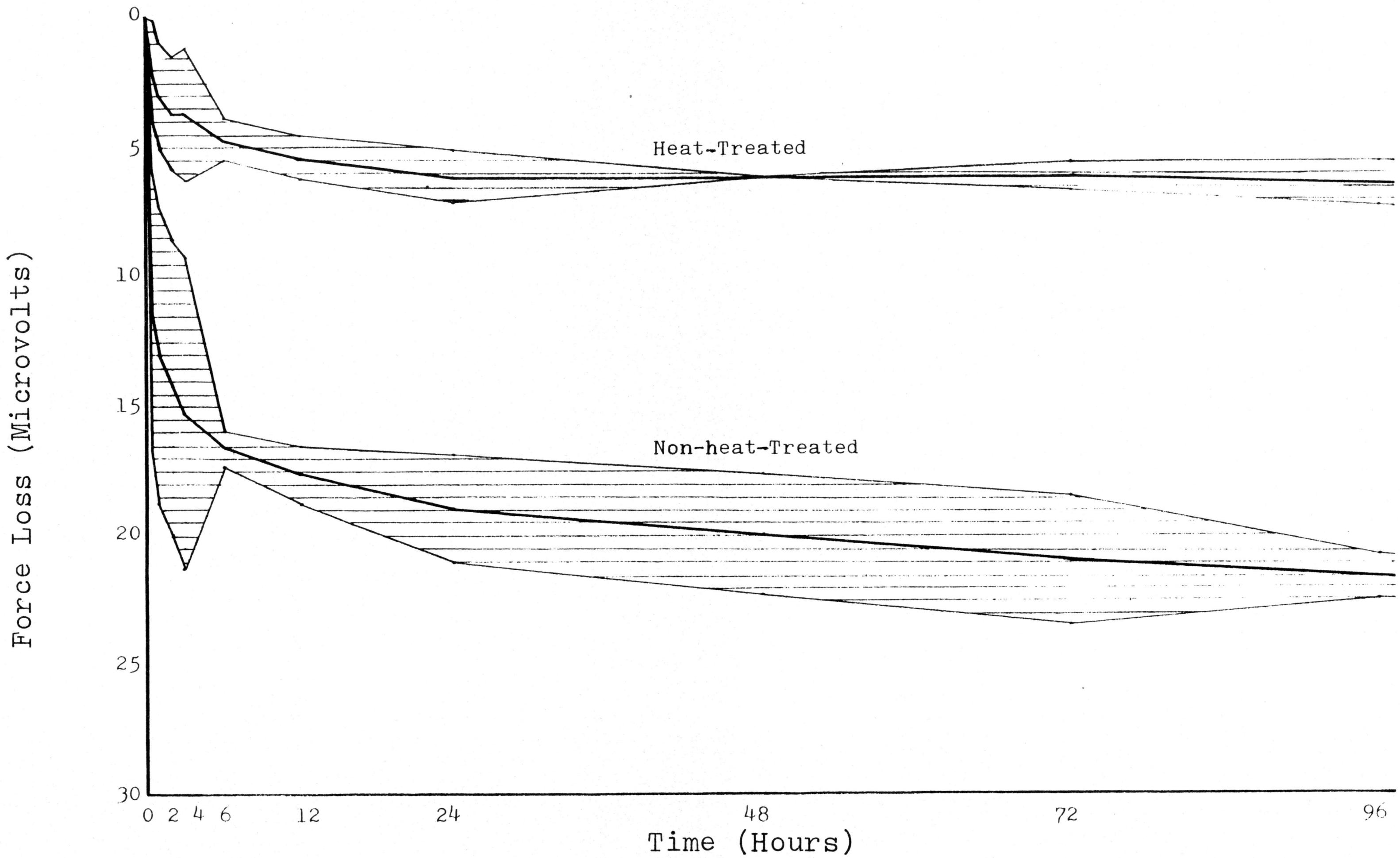

Figure 15. Mean Force Loss Curve of the Average of <u>ALL THREE TYPES OF WIRE</u> (Blue Elgiloy, Permachrome Standard Stainless Steel, and Multiphase) with Pooled Standard Deviations (Shaded Area) Showing the Heat-Treated and Non-Heat-Treated Condition.

1 g Force Loss = 5.4 Microvolts

time (T_1). For example, 0-3 is the accumulative effect from T_1 to the end of the third hour of activation. The next three readings were from the beginning of the first indicated hour to the beginning of the second indicated hour. The remaining six readings represent the changes taking place in a 24-hour period starting at the beginning of the day indicated.

The data were analyzed using the ANOVA (analysis of variance) program from the SPSS computer package with loss of force as the dependent variable and wire condition and load cell as independent variables. It was felt that there might be interactions between load cell, wire and condition; thus interaction terms were included in the analysis. The interaction terms were not found to be statistically significant.

A second analysis eliminating the interactions found that condition of the wire (heat-treated vs. non-heat-treated) significantly affected the loss of force. However, neither wire composition nor load cell were found to be statistically significant (Table IV). This confirmed the consistency of the load cells in producing the desired measurements.

Table IV was constructed to show the "p" values (level of significance) for the three independent variables. A "p" value of 0.05 or less relates to changes greater than what would be considered acceptable variation in the equipment. The "p" values of 0.1 and less are recorded under the three variables and across from the time periods represented.

All the "p" values under the wire column were greater

TABLE IV

"p" Values for ANOVA Testing Change in Microvolts for Indicated Time Periods Using Wire, Condition, and Cell for Independent Variables.

Time	Wire	Condition	Cell
*0-0.5 Hrs.	NS+	0.000	NS
0-1	NS	0.000	NS
0-2	NS	0.000	NS
0-3	NS	0.000	NS
**3-6	NS	NS	NS
6-12	NS	NS	NS
12-24	NS	0.066	0.001
***D2	NS	0.019	NS
D3	NS	0.066	NS
D4	NS	NS	NS
D5	NS	NS	NS
D6	NS	NS	NS
D7	NS	0.046	NS
0-7 Days	NS	0.000	NS

*Lowest reading during indicated time period

**Average reading during indicated time period

***Average reading during day 2, etc.

+Not significant

than 0.05 and, therefore, indicate that the type of wire had no effect on the observed decreases in force during the time period. Under the load cell column all but one of the "p" values show insignificance to the effect of the load cell on the observed decreases. The time period of 12-24 hours shows a "p" value well in the significant (p=0.001) range. This indicates that the load cell had a significant effect on the data during this time period, which at this time is unexplainable. Even though this time period shows apparent significance for load cell effect, when the entire time lapse, 0-7 days, is observed, no significance is found.

In the condition column a very different set of numbers from the other two columns was observed. The first four time periods showed very high levels of significance due to the condition of the wire. The time periods of 3-6 hours and 6-12 hours showed no level of significance. This was probably due to the fact that they were of short duration, three and six hours, and far enough removed from T_1 to realize no significant change. The D2 time period, however, showed a level of significance (p=0.019). This was probably because it was the first test that included 24 hours of time. The 12-hour time period just prior to D2 approached significance and the 24-hour time period just after D2 did also. This would indicate that the action was slowing down during the first two or three days to an insignificant level by day four. Time period D4, 5, and 6 showed no level of significance. Time period D7 showed a low level of significance (0.046) which is unexplainable. Looking at the overall time lapse, 0-7, the condition variable had an extremely high level of significance (p=0.000) while the wire and cell variables had no level of significance.

To interpret Tables I, II and III, they must be broken down into two catagories: 1) intrawire comparisons and 2) interwire comparisons. The second catagory can be further divided into three groups: A) heat-treated wire vs. heat-treated wire B) non-heat-treated wire vs. non-heat-treated wire C) non-heat-treated wire vs. heat-treated wire.

In the catagory of intrawire comparisons, very similar results with all three wires were observed. The non-treated wire lost much more force and lost it more rapidly than did the heat-treated wires (Figs. 12, 13, 14).

Blue Elgiloy lost 9% of its total force in the non-heat-treated state compared to only 2% of its total force in the heat-treated state, a total of 4.5 times more. Similar results are seen for Multiphase (11% vs. 3%), and even the Permachrome Standard Stainless Steel wire lost two times (6% vs. 3%) as much force in the non-heat-treated state (Tables I, II, III).

The rate at which this force loss occurred is also of interest. All three wires in the non-heat-treated condition lost approximately 50% of their force in the first 30 minutes and approximately 25% more in the next 4½ hours. In contrast to this, the heat-treated wires lost their force at approximately one-half this rate. Heat-treated Blue Elgiloy lost

20% in the first 30 minutes and 60% over the next 4½ hours. Permachrome Standard Stainless Steel lost 30% in the first 30 minutes and 30% over the next 4½ hours. Multiphase lost 25% in the first 30 minutes and 30% over the next 4½ hours. The general loss of force in the heat-treated condition was slower in rate and much smaller in magnitude than that in the non-heat-treated condition (Figs. 12-15).

The second category, that of interwire comparison, was divided into three groups. The first group dealt with a comparison of heat-treated wires with other wires in this same condition. The properties of the three types of wire tested proved to be very similar. Blue Elgiloy lost 2% of its total force while the other wires both lost only 3%. Their rate of loss was also very similar: in the first 30 minutes of the test they lost 1/5, 1/4, and 1/3 of their total loss for Blue Elgiloy, Multiphase, and Permachrome Standard respectively. These figures were similar enough to clinically ignore the differences.

The next group in this category was non-heat-treated wires vs. non-heat-treated wires. The data in Tables I, II, and III indicated that the non-heat-treated wires, when compared to each other, have similar rates of force loss, but differ somewhat in their ability to maintain their initial force. The rate of force loss was approximately 50% in the first 30 minutes, 60% in the first hour and 70% in the first two hours for all three wire types. The Multiphase did, however, lose its force over a longer period of time than did the other two wires.

The amount of force lost was very similar in Multiphase and Blue Elgiloy wire (11% and 9% respectively) while the amount lost by Permachrome Standard Stainless Steel was only 6%.

The final group of comparisons in category 2 is concerned with non-heat-treated wire vs. heat-treated wire. This component was found to be statistically significant. In its discussion, Tables IV and V as well as Tables I, II, and III must be utilized.

Table V was constructed to show the difference between the wire conditions. The means of the three wires in the non-heat-treated conditions were averaged and placed under the appropriate column. The means for the heat-treated wires were also averaged and placed under their appropriate column. A pooled standard deviation was calculated for each condition and placed under another column across from the time period represented. This material was incorporated into Figure 15.

From examination of Tables I, II, III, IV, V and in conjunction with Figure 15, it is apparent that the heat-treated condition of any of the wires tested is superior to the non-heat-treated condition of any other wire for the procedure tested. For example, Permachrome Standard Stainless Steel, the most superior (in terms of force loss) of the non-heat-treated wires, still lost twice as much force as the most inferior heat-treated wire.

TABLE V

Mean Force Loss in Microvolts of the Average of ALL THREE TYPES OF WIRE (Blue Elgiloy, Permachrome Standard Stainless Steel, and Multiphase) with Pooled Standard Deviations Showing the Heat-Treated and Non-Heat-Treated Condition.

Time	Non-heat-Treated		Heat-Treated	
	Mean	Pooled SD+	Mean	Pooled SD
*0-0.5 Hrs.	11.3	5.4	2.0	1.9
0-1	13.0	5.7	3.0	2.1
0-3	15.3	6.0	3.7	2.6
**3-6	1.3	0.7	1.0	0.8
6-12	1.0	1.1	0.7	0.9
12-24	1.3	2.1	0.7	1.0
***D2	1.0	2.3	0.0	0.0
D3	1.0	2.5	0.0	0.5
D4	0.7	0.8	0.3	0.8
D5	0.3	0.8	0.3	1.4
D6	0.3	0.3	0.0	0.3
D7	0.3	0.4	0.0	0.0
0-7 Days	23.3	6.3	7.3	5.2

+Standard Deviation

*Lowest reading during indicated time period

**Average reading during indicated time period

***Average reading during day 2, etc.

1 g force = 5.4 microvolts

A similar comparison of any other two wires yields even more impressive results. Multiphase, the worst (in terms of force loss) non-heat-treated wire, lost six times as much force as did Blue Elgiloy, the best heat-treated wire.

CHAPTER V

CONCLUSIONS

1. The results of this study indicated that all wires tested gave similar force relaxation rates when used in the same conditions (heat-treated or non-heat-treated).

2. The force produced by the orthodontic wires tested decreased rapidly for 24-48 hours and this decrease in force had practically stopped in a period of one week. The highest loss was 11% of the total activation force. This could be significant if the resulting force falls below the optimum force for tooth movement.

3. The heat treatment of orthodontic wire for stress relief as recommended by the manufacturer decreased the force loss of the wires from 50-80%, indicating that the heat treatment is valuable for increasing force retention properties of the tested wires.

4. The intrinsic deficiencies in the orthodontic wires tested are responsible for 9-11% force loss in the non-heat-treated condition and 2-3% of force loss in the heat-treated condition when tested over a one-week period.

5. Any one of the wire types has force relaxation properties as good as the next. Based on the findings in this experiment, the wire type makes little or no difference as to the force relaxation rate and quantity.

CHAPTER VI

SUMMARY

Three types of orthodontic wires were tested under heat-treated and non-heat-treated conditions for force relaxation rates. An electronic apparatus was used to measure and monitor the force produced by the activated wires. Data were statistically analyzed by computer to give means, standard deviations and an analysis of variance. The data collected indicated that the type of wire had no significant influence on the behavior of the test wire, but that the heat-treated condition of the wire dictates the wire's properties of force relaxation under the type of load and conditions of the test. Non-heat-treated wires lost 9-11% of their force in one week, while heat-treated wires lost only 2-3% of their total force in the same time lapse.

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APPENDIX A

Appendix A

TableVI Recorded Millivolts per Time Period by Wire #, Load Cell #, and Condition, Trial I.

Wire	1	2	3
Load Cell	1	2	3
Treatment	1	2	2
Zero 1	+0.001	+0.000	+0.000
Gram wts.	+0.280	+0.279	+0.250
Zero 2	+0.000	+0.000	+0.000
I	+0.260	+0.277	+0.251
0.5	+0.258	+0.274	+0.246
1	+0.256	+0.274	+0.245
2	+0.255	+0.273	+0.244
3	+0.255	+0.273	+0.243
3-6	+0.254	+0.272	+0.241
6-12	+0.252	+0.271	+0.240
12-24	+0.251	+0.271	+0.240
D2	+0.250	+0.271	+0.240
D3	+0.250	+0.271	+0.240
D4	+0.250	+0.271	+0.240
D5	+0.250	+0.271	+0.240
D6	+0.249	+0.271	+0.240
D7	+0.248	+0.271	+0.240
F	+0.248	+0.271	+0.240
Zero 3	-0.001	+0.002	+0.005
Gram wts.	+0.279	+0.280	+0.244
Zero 4	+0.000	+0.002	+0.005

Key: See Appendix B

Table VII Recorded Millivolts per Time Period by Wire #, Load Cell #, and Condition, Trial II.

Wire	3	1	2
Load Cell	3	1	2
Treatment	1	2	1
Zero 1	+0.000	+0.002	+0.000
Gram wts.	+0.250	+0.273	+0.280
Zero 2	+0.000	+0.000	-0.001
I	+0.253	+0.273	+0.273
0.5	+0.239	+0.270	+0.264
1	+0.236	+0.269	+0.262
2	+0.235	+0.269	+0.261
3	+0.234	+0.268	+0.261
3-6	+0.233	+0.267	+0.260
6-12	+0.233	+0.266	+0.258
12-24	+0.233	+0.265	+0.257
D2	+0.232	+0.265	+0.257
D3	+0.230	+0.264	+0.255
D4	+0.227	+0.263	+0.254
D5	+0.226	+0.263	+0.253
D6	+0.226	+0.263	+0.253
D7	+0.226	+0.263	+0.253
F	+0.226	+0.263	+0.253
Zero 3	-0.005	-0.001	-0.002
Gram wts.	+0.246	+0.272	+0.279
Zero 4	-0.004	-0.001	-0.002

Key: See Appendix B

Table VIII Recorded Millivolts per Time Period by Wire #, Load Cell #, and Condition, Trial III.

Wire	2	3	1
Load Cell	1	2	3
Treatment	1	1	1
Zero 1	+0.000	+0.000	+0.000
Gram wts.	+0.273	+0.278	+0.250
Zero 2	+0.000	+0.000	+0.001
I	+0.273	+0.278	+0.251
0.5	+0.264	+0.267	+0.231
1	+0.263	+0.267	+0.228
2	+0.261	+0.264	+0.227
3	+0.260	+0.263	+0.226
3-6	+0.259	+0.260	+0.225
6-12	+0.259	+0.260	+0.225
12-24	+0.257	+0.257	+0.225
D2	+0.257	+0.255	+0.221
D3	+0.257	+0.254	+0.221
D4	+0.257	+0.252	+0.221
D5	+0.257	+0.250	+0.221
D6	+0.257	+0.250	+0.220
D7	+0.257	+0.249	+0.219
F	+0.257	+0.249	+0.219
Zero 3	+0.000	-0.003	+0.001
Gram wts.	+0.274	+0.276	+0.253
Zero 4	+0.000	-0.003	+0.002

Key: See Appendix B

Table IX Recorded Millivolts per Time Period by Wire #, Load Cell #, and Condition--Trial IV.

Wire	2	3	1
Load Cell	3	1	2
Treatment	2	2	2
Zero 1	+0.000	+0.000	+0.000
Gram wts.	+0.250	+0.275	+0.280
Zero 2	+0.000	+0.000	+0.000
I	+0.250	+0.279	+0.278
0.5	+0.245	+0.277	+0.278
1	+0.244	+0.277	+0.278
2	+0.244	+0.276	+0.278
3	+0.244	+0.275	+0.278
3-6	+0.244	+0.274	+0.278
6-12	+0.244	+0.278	+0.278
12-24	+0.244	+0.271	+0.278
D2	+0.244	+0.271	+0.278
D3	+0.244	+0.271	+0.278
D4	+0.244	+0.269	+0.278
D5	+0.244	+0.269	+0.278
D6	+0.244	+0.269	+0.278
D7	+0.244	+0.269	+0.278
F	+0.244	+0.269	+0.278
Zero 3	+0.002	-0.001	+0.001
Gram wts.	+0.252	+0.274	+0.281
Zero 4	+0.002	-0.001	+0.000

Key: See Appendix B

Table X Recorded Millivolts per Time Period by Wire #, Load Cell #, and Condition--Trial V.

Wire	1	3	1
Load Cell	3	1	2
Treatment	2	1	1
Zero 1	+0.000	+0.002	+0.000
Gram wts.	+0.249	+0.276	+0.279
Zero 2	+0.000	+0.002	+0.001
I	+0.248	+0.275	+0.275
0.5	+0.248	+0.262	+0.261
1	+0.247	+0.261	+0.260
2	+0.247	+0.259	+0.258
3	+0.247	+0.258	+0.257
3-6	+0.246	+0.256	+0.256
6-12	+0.246	+0.254	+0.254
12-24	+0.246	+0.249	+0.253
D2	+0.246	+0.248	+0.252
D3	+0.246	+0.246	+0.251
D4	+0.246	+0.245	+0.250
D5	+0.242	+0.245	+0.249
D6	+0.242	+0.244	+0.249
D7	+0.242	+0.244	+0.248
F	+0.242	+0.244	+0.248
Zero 3	-0.001	+0.001	-0.001
Gram wts.	+0.248	+0.276	+0.278
Zero 4	-0.001	+0.001	-0.002

Key: See Appendix B

Table XI Recorded Millivolts per Time Period by Wire #, Load Cell #, and Condition, Trial VI.

Wire	2	2	3
Load Cell	1	3	2
Treatment	2	1	2
Zero 1	-0.001	-0.002	+0.000
Gram wts.	+0.275	+0.248	+0.279
Zero 2	-0.001	-0.002	+0.000
I	+0.276	+0.247	+0.275
0.5	+0.273	+0.237	+0.275
1	+0.272	+0.236	+0.274
2	+0.271	+0.235	+0.274
3	+0.270	+0.233	+0.274
3-6	+0.268	+0.232	+0.274
6-12	+0.265	+0.231	+0.274
12-24	+0.263	+0.231	+0.274
D2	+0.263	+0.231	+0.274
D3	+0.263	+0.231	+0.273
D4	+0.262	+0.231	+0.273
D5	+0.261	+0.231	+0.273
D6	+0.260	+0.231	+0.273
D7	+0.260	+0.231	+0.273
F	+0.260	+0.231	+0.273
Zero 3	+0.004	-0.004	+0.001
Gram wts.	+0.278	+0.247	+0.279
Zero 4	+0.002	-0.003	+0.000

Key: See Appendix B

APPENDIX B

Appendix B

Wire	1	Blue Elgiloy
	2	Permachrome Standard Stainless Steel
	3	Multiphase
Load Cell	1	Load Cell #1
	2	Load Cell #2
	3	Load Cell #3
Treatment	1	No heat treatment
	2	Test wire heat treated to manufacturers specifications.
Zero	1	Zero reading before test before Gram wts. 1 reading
Gram wts.	1	Reading for a known wt. of 50 grams before test.
Zero	2	Zero reading before test and after Gram wts. 1 reading.
	I	Initial force applied by activated test wire.
	0.5	Reading at time 0.5 hours.
	1	Reading at time 1 hour.
	2	Reading at time 2 hours.
	3	Reading at time 3 hours.
	3-6	Lowest reading between hour 3 and hour 6.
	6-12	Lowest reading between hour 6 and hour 12.
	12-24	Lowest reading between hour 12 and hour 24.

	D2	Average reading during day 2.
	D3	Average reading during day 3.
	D4	Average reading during day 4.
	D5	Average reading during day 5.
	D6	Average reading during day 6.
	D7	Average reading during day 7.
	F	Final reading
Zero	3	Zero reading after test and before Gram wts. 2 reading.
Gram wts.	2	Reading for a known wt. of 50 grams after the test.
Zero	4	Zero reading after Gram wts. 2 and after test.

APPENDIX C

APPENDIX C

Tables I, II, and III have mean columns which are made up of the mean of three different numbers rounded off to the nearest microvolt. The number at the bottom of each column is the mean of three numbers representing the total drop of microvolts for the entire test time. This means then that the sum of the numbers in any column may not add up to equal the number at the bottom of that column.