TEMPERATURE PROFILE CHARACTERIZATION OF BATHS IN THREE DIMENSIONS

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ABSTRACT

Traceable temperature measurements require that temperature sensors should be regularly calibrated with respect to the internationally agreed temperature standards . To do this, two methods are used i.e comparison calibrations and fixed point calibrations. The latter is the most common method used by secondary temperature calibration laboratories. Liquid baths are the main calibration equipment that directly affect the measurement uncertainty in temperature calibrations. Therefore, the characteristics of baths need to be well investigated and understood.

The temperature profile and stability of liquid baths are one of the most important contributions to the calibration uncertainty of platinum resistance thermometers, digital thermometers, liquid-in glass thermometers, thermocouples and etc. .

In general, commercial baths only present a two-dimensional bath profile or sometime just a stability of the baths are given However, thermometers, thermocouples and etc. are immersed into the body of the bath. Thus the depth or z axis is also very important.

In this work a measurement system has been designed using three-stepper motors and a data acquisition system (DAS). The DAS is developed using object oriented algorithms called a three dimensional (3-D) scanning system. The 3-D scanning system is home-made and used in conjunction with a Hart Scientific reference platinum thermometer, the temperature profiles and stability of several types of baths: water, oil and salt were carried out in the temperature range 30 °C to 450 °C. This will then contribute towards a more accurate uncertainty budget.

ÖZET

İzlenebilir sıcaklık ölçümleri, sıcaklık ölçümlerinde kullanılan sıcaklık sensörlerinin düzenli olarak uluslararası alanda Kabul edilen sıcaklık standardları ile kalibre edilmesi ile mümkündür. Bunun gerçekleşebilmesi için iki method kullanılmaktadır, örnğ: karşılaştırmalı ve sabit nokta metodu. Karşılaştırma metodu ikinci derece kalibrasyon laboratuvarları tarafından en çok kullanılan bir metotdur. Bu metotda, sıvı banyoları en çok kullanılan kalibrasyon aletleri olup, sıcaklık ölçümlerininin belirsizliğini direk etkilemektedir. Bu nedenle, sıvı banyolarının karaekteriktiksel özelliklerinin iyi belirlenmesi ve anlaşılması gerekmeketedir.

Platin Direnç Termometrelerin, Göstergeli Sıcaklık Sensörlerin, cam termometrelerin ve ısılçiftlerin kalibrasyonlarında kullanılan sıvı banyolara ait sıcaklık profilleri ve kararlılık değerleri, kalibrasyon ölçüm belirsizliği hesaplamaları açısından önemlidir .

Ticari amaçla kullanılan sıvı banyoları genellikle iki boyutlu sıcaklık profilini veya sıvı banyosunun karalılığını sunarlar. Bununla beraber ısıl cifler termometreler ve benzeri cihazlar sıvı banyasunun içerisine daldırıldıklarından, derinlik veya z boyutu önem kazanmaktadır.

Bu çalışmada, ölçüm düzeneği olarak üç adet step motor kullanılarak ve uygun yazılım diliyle çalışan laboratuvar yapımı 3 boyutlu tarayıcı system kurulmuştur. Üç boyutlu tarayıcı system, Hart scientific model Referans Platin direnç termometresi ile birlikte kullanılarak, sıvı banyoların: su, yağ ve tuz, sıcaklık profilleri ve kararlılık değerleri 30 ° ile 450 °C sıcaklık aralığında tespit edildi.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF SYMBOLS

DAS	Data Acquisition System
ITS	International Temperature Scale
ITS-90	International Temperature Scale 1990
S	Entropy
Q	Heat
T	Absolute Temperature
K	Kelvin
t	Celsius Temperature
σ	Standard Deviation
μ	Mean
σ^2	Variance
s	Experimental standard deviation
R	Resistance
3-D	Three Dimensional
VUI	Visual User Interface
PIC	Peripheral Interface Controller

1. INTRODUCTION

The main purpose of this study is to construct a new device for detailed data collection by the existing metrology calibration techniques. Metrology is developing rapidly in Turkey. Today liquid and salt baths are among the most important calibration equipment in temperature metrology. Temperature calibration laboratories perform immersion tests for calibrating thermometers. During these tests, the most important error is the temperature fluctuation between two different probes, which depends upon the distance, and the magnitude of the temperature fluctuation, this forms the uncertainties. The purpose of our study is to construct a general scanning system in three dimensions. Commercial data only provide information in two dimensions; thus, no depth information is available, which may be used in baths of different types and dimensions, manufactured by various companies. In the system constructed here, the step interval starts from 1.5 mm, can be adjusted to any desired interval, and is capable of scanning the bath in three dimensions. The system is composed of three stepper motors remotely controlled via software. By using this device, the locations of the bath, which are more stable, can be determined. Thus, the position and separation at which two probes to be calibrated must stay with respect to each other can be realized. Obtaining the three dimensional heat fluctuation distribution graph of any bath is a great advantage for the laboratory worker. A similar study was published in October 20, 2005 under the title ‘Automated system for measuring temperature inside ITS-90 fixed point cells [1]. This system was one-dimensional and is a developed stage of an immersion test.

2. PRELIMINARIES

2.1. Measurement

From the beginning of civilization, communities have tried to use some units to express their measurement. The most popular of these units were body parts like feet, palms, nails, etc. which help to communicate measures of length. This might work well for textile merchants in ancient times, but in some cases, that is not enough. Today we must use more precise and rigid definitions. Assume that we have a nuclear or chemical reactor and the efficiency of this reactor depends on the temperature in the cell or we have a plane whose safety depends on the temperature of its fuel. We have to know the precise values of the temperature of these objects; however, under these conditions the temperature between human body and the fuel or the reactor cannot be compared to make a good decision, since the latter is so variable. Another way of identifying the reason for making a measurement is to determine how it affects our actions. For industrial measurements, the answer is simple because measurements have the fundamental meanings of making contracts. Customers and dealers make decisions for buying or selling goods by looking at the quantity and price ratio. The accepted metrological definition of a measurement is addressed in two parts:

2.1.1. Measurement:

The set of operations having the object of determining a value of quantity [2].

2.1.2. Result of a measurement:

The value attributed to a measureand obtained by measurement [2].

An alternative definition that applies to both processes and the result:

2.1.3. Measurement (alternative definition):

The symbolic representation of a state, event or attribute to aid in making a decision [2].

This definition highlights three important aspects of measurement not apparent from the first two definitions:

The results of a measurement need not to be numeric: grade A, color red and sodium are all legitimate measurement results in the appropriate context. One of the most valuable aspects of symbolic representations is the symbols that are used in the models to make predictions. Mathematical models and numeric symbols particularly help to quantify predictions that might otherwise be qualitative or subjective.

Every measurement has a purpose. This is the distinction sought between a meaningful measurement and the meaningless assignment of a number. In great many measurements, especially outside the calibration laboratory, the purpose influences the design and outcome of the measurement. Consequently, measurement results may have meaning only within the context of that purpose. Results used for other purposes or gathered without any purpose are potentially dangerous.

Decisions are associated with risks and rewards. This highlights the need to know the uncertainty in a measurement in order to assess the risk or optimize the measurement [2].

Measurements with definition problems are often the source of the argument.

2.2. Measurement Scales

There are four kinds of measurement scales. These are Nominal Scales, Ordinal Scales, Interval Scales and Metric Scales.

2.2.1. Nominal Scales

In Nominal Scales, the results generally indicate a class. A good example would be, in a football game, goalkeepers generally wear the uniform number one. This number has no meaning related to the performance of the player or it does not represent the best player in the team; it only shows us that if a player wears a uniform with number one on it, we generally understand that he or she is a goalkeeper. Other examples for nominal scales are colors, name of plants, etc.

2.2.2. Ordinal Scales

Ordinal Scale results also need not to be numerical, it is a comparative scale. Some examples of this type of scale are examination grades, credit ratings, early temperature scales.

The International Temperature Scale of 1990 (ITS-90)[3] is also an ordinary scale where the defined points are various at melting and freezing points of pure substances, and the interpolating instruments include platinum resistance thermometers, vapor-pressure thermometers and radiation thermometers. With many ordinal measurements, the response of the interpolating instrument is known to be non-linear but it is still possible to tell when one sample has a greater concentration of a particular compound than another or higher temperature than another does [2].

2.2.3. Interval scales

It is defined as a linear comparative scale. We choose an arbitrary beginning point and we take equal differences to the end of our scale. One of the earliest thermodynamic temperature scales, the centigrade scale, was an interval scale based on the definition of the melting point and the boiling points of water at 0ºC and 100ºC respectively. Because interval scales gave meaning to intervals for the first time, these are the first scales that allowed normal statistics to be performed; that is, to calculate means and standard deviations [2].

2.2.4. Metric scales

In metric scales, ratios and fractions can be discussed. SI scales are good examples of metric scales. In the metric scale, a standard is first defined, and then some mathematical expression assign ratios with respect to that standard is used. This gives a meaningful result. In The Bureau International des Poids et Mesures (BIPM) for the mass unit, for example, a standard prototype kilogram is maintained and all the mass scales is defined in terms of this prototype. Due to the very large range of values encountered, it is often convenient to transform metric measurements into a logarithmic scale. These scales are typically constructed as

Value on log scale = constant x log (value/reference value) [2]

The meaning of the constant multiplier and the reference value must be defined. On these scales, equal intervals correspond to constant multiplying factors of the underlying metric quantity. In astronomy, magnitudes are used to understand the brightness of stars. Five steps of visual magnitude correspond to 100 times decrease in the brightness. Metric scales are also known as, ratio scales, and the literal translation of the word metrology, from the Greek *metrologi*a, is the study of ratios [2].

2.3. Thermodynamic Origin Of Temperature

Temperature is defined according to the Zeroth law of thermodynamics. "If two systems are in thermal equilibrium and one of those systems is in thermal equilibrium with a third system, then all three systems are in thermal equilibrium with each other"[4]. To define these systems in thermal equilibrium temperature is used. By replacing the third system with a thermometer, the zeroth law can be written as follows: if two systems have the same temperature even if they are not in contact with each other, then the two systems are in thermal equilibrium. The second law of thermodynamics is used to define absolute temperature, *T*.

$$\mathrm{d}S \geq \delta\, Q/T \tag{2.1}$$

Above d*S* is the change in entropy and δQ is the change in heat [5,6]. This equation gives a metric temperature scale, but requires a description of magnitude and sign in order to define the unit. The Systéme International d'unites (SI) defines Kelvin, symbol K, by fixing the temperature of the triple point of water to 273.16 K[6]. The Celsius temperature, *t*, is related to the absolute temperature by

$$t/^{\circ}\mathrm{C} = T/\mathrm{K} - 273.15 \tag{2.2}$$

and the unit is the degree Celsius, with the symbol ºC[3,6,7,13]. Celsius scale uses the ice point 0ºC and the triple point of water is 0.01ºC [6]. However since the thermodynamic

thermometers cannot show precise results, The International Temperature Scale, ITS[3,6], is defined. All the temperature measurements must be traceable to the current ITS [2,3,8].

A thermodynamic analysis of Carnot engines shows that the efficiency of reversible heat engines depends only on temperature ratio [2]. The ratio of heat Q_1 taken in at a high temperature $f(\theta_1)$ to the heat Q_2 given out at a lower temperature $f(\theta_2)$ depends on the ratio of the temperatures [2]:

$$\frac{Q_1}{Q_2} = \frac{f(\theta_1)}{f(\theta_2)}\ , \tag{2.3}$$

where θ is any empirical measure of temperature [2]. Kelvin's breakthrough was to recognize that the relationship could be used to define the temperature T [2,7,13]:

$$\frac{Q_1}{Q_2} = \frac{T_1}{T_2} \tag{2.4}$$

Kelvin was also able to show that this definition leads to an equation for ideal gases [2]:

$$PV = \text{constant x } T \tag{2.5}$$

This is the basic definition of temperature; however, it took the combined work of Maxwell, Boltzman, and Gibb [2]. The combination of these equations and rules are known as statistical mechanics, describing the movement and collisions of individual atoms in a closed box [2]. If the system is in thermal equilibrium in a closed box, than the mean kinetic energy of all atoms must be the same.

$$PV = \text{constant x } <mv^2/2>, \tag{2.6}$$

Where $mv^2/2$ is the average kinetic energy of each atom in the gas. Comparison of these two equations (2.5-2.6) shows that the temperature is proportional to the average kinetic energy of each atom [2]. Below are some thermometer equations and thermodynamic relationships.

Thermometer	Thermodynamicrelation
For Gas Thermometer: where, P is pressure; V is volume. n; is the number of molecules and T; is temperature	$PV = nKT = NRT$
For Noise Thermometer: where $\overline{V^2}_T$ is mean square noise voltage versus real part of impedance, Z; bandwidth, Δf, and temperature	$\overline{V^2}_T = 4kT\mathrm{Re}(Z)\,\Delta f$

(2.7)

2.4. Metrological temperatures

Metrological temperature measurements are nearly empirical. The thermometer measures data according to type and construction of thermometer. Practically it is impossible to eliminate the unwanted background data. However, with the use of many approximations it is practical to collect the most important data very close to the physical definition. As a result, measurements from different parts of the country and even the globe are comparable. Thus, meaningful measurements must use some protocols, which include traceability and uncertainty.

2.5. Traceability

Today traceability is one of the most important factors for manufactured goods. Global companies produce their products in many different countries, to lower the price; all of these products must conform same standards to attain a better sale ratio and nominal value for the product. In metric scales, the traceability problem is relatively straightforward. A single standard related to the measurement of the product must be obtained. Ordinary scales must be used often. These have some related problems. They require a minimum of two standards, and in many cases, they require an approved or specified interpolating instrument. Imagine that a biological product calibration laboratory and some length or temperature product must be calibrated. Being a reliable laboratory our measuring standards must be traceable to primary standards in order to reduce errors to

acceptable values and minimize risks for the laboratory results and safety. The ISO definition of traceability is:

Traceability:

The property of the result of a measurement or the value of a standard whereby it can be related to stated references, usually national or international standards, through an unbroken chain of comparisons all having stated uncertainties [2].The ISO definitions note where the chain begins and ends. It is about the measurement result, not about the measurement device. Traceability requires all measuring devices to use the same scale [2]. Today most devices use SI unit scales, but that does not mean that all measuring devices measure the same data and the same traceable values. It is about uncertainty. The quality of the measurements depends on the quality of the measuring device, and the quality of the measuring device depends on its uncertainty. Lower uncertainty makes the device more precise. Today most of the measuring devices have calibration certificates that indicate their traceabilities, uncertainties and working conditions; however the certificate does not guarantee that the measurement has been performed with due care and attention. Finally, the laboratories must be traceable to national accreditation bodies, information about this can be found in ISO 17025 under 'general requirements for the competence of testing and calibration laboratories'. To summarize all the information given above, "The ability to demonstrate the accuracy of a measurement result in terms of appropriate national or international standards" [2].

2.6. Uncertainty in Measurement

No measurement of a continuous physical variable is exact. To overcome this problem some mathematical tools are used. Uncertainty analysis requires statistical techniques and some mathematical models to process the source of errors and other environmental conditions that change the result of the measurement. The most common way of minimizing errors is to make the measurement several times.

2.6.1. Uncertainty of measurement

The parameter associated with the result of a measurement that characterizes the dispersion of the values that could reasonably be attributed to the measurand [2].

There are two types of uncertainties. Type A uncertainties, which deal with statistical analysis of actual measurements; and Type B uncertainties, which use information from handbooks, catalogs, manuals or physical theories.
The other factor that affects measurements is measurement error. There are random errors and systematic errors.

2.6.2. Systematic error:

The mean of a large number of repeated measurements of the same measurand minus the true value of the measurand [2].

2.6.3. Random error:

The result of a measurement minus the mean of a large number of repeated measurements [2]. Generally, uncalibrated equipment, improper calibration techniques or environmental conditions cause systematic errors. Unpredictable data scattering is known as random error.

2.6.4. Correction:

The value added algebraically to the uncorrected result of a measurement to compensate for systematic error [2]. By repeating measurement, a data distribution will appear. The mathematical meaning of this distribution is the range of possible results. As the number of measurement is increased, the shape of the distribution becomes better defined. Below some distributions are given, first distribution is a discrete distribution; μ is the mean, $P(X_i)$ is the probability of obtaining the result X_i and N is the number of measurements [2].

$$\mu = \sum_{i=1}^{N} X_i P(X_i), \tag{2.8}$$

The width of the distribution is characterized by variance and is calculated as

$$\sigma^2 = \sum_{i=1}^{N} (X_i - \mu)^2 P(X_i) \tag{2.9}$$

σ is called the standard deviation of the distribution and is proportional to the width [2].

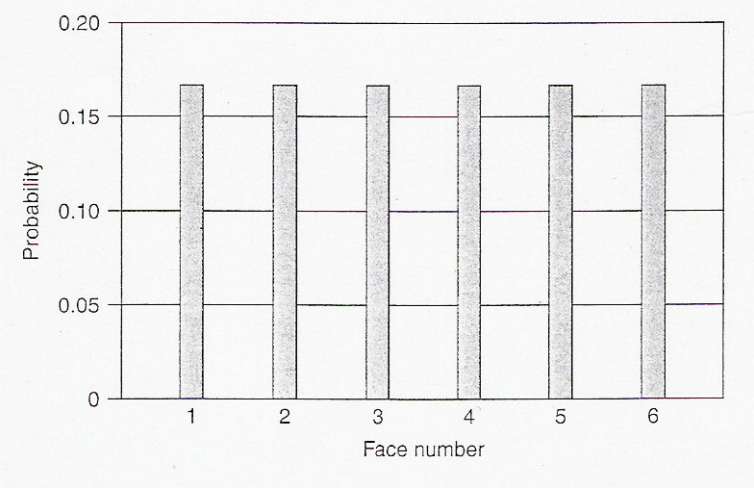


Figure 2.1 discrete distribution

The figure 2.1 is an example of a discrete distribution. It shows the possible outcomes of the throw of a die. The second type of distribution is continuous distribution. Generally, the quantities that are measured are not discrete, but continuous. In continuous distributions, the data collected vary within a certain range. The probability of finding the results under the curve of the total area is equal to 1 or 100%. The curve is called the probability density function, *p(x).* The probability of finding a result within an interval between X_1 and X_2 is given by the area under *p(x)* between X_1 *and* X_2*:*[2].

$$P(X_1 < \chi < X_2) = \int_{x_1}^{x_2} p(x)dx. \tag{2.11}$$

For a rectangular distribution the probability of finding the result *x* between X_1 and X_2 is [2]

$$P(X_1 < x < X_2 = \frac{X_2 - X_1}{X_H - X_L}, \tag{2.12}$$

This is the ratio of the area in the interval to the total area. For continuous distributions the mean is calculated as [2].

$$\mu = \int_{-\infty}^{+\infty} xp(x)dx.$$

and the variance is

$$\sigma^2 = \int_{-\infty}^{+\infty} (x-\mu)^2 p(x)dx. \tag{2.13}$$

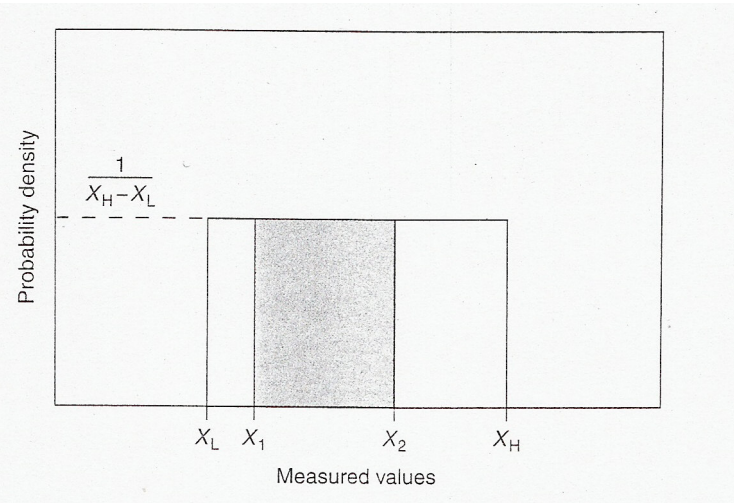


Figure 2.2 rectangular distribution

The rectangular distribution is a good example of a continuous distribution

The probability density for the rectangular distribution is

$$p(x) = \begin{cases} 0 & x < X_L \\ \dfrac{1}{X_H - X_L} & X_L < x < X_H \\ 0 & x > X_H \end{cases} \tag{2.15}$$

The mean is

$$\mu = \frac{1}{X_H - X_L}\int_{X_L}^{X_H} x dx = \frac{X_H + X_L}{2} \tag{2.16}$$

The variance is

$$\sigma^2 = \frac{1}{X_H - X_L}\int_{X_L}^{X_H} (x - \frac{X_H + X_L}{2})^2 dx = \frac{(X_H - X_L)^2}{12} \tag{2.17}$$

The standard deviation is

$$\sigma^2 = \frac{1}{\sqrt{3}}\frac{(X_H - X_L)}{2} \approx 0.29(X_H - X_L) \tag{2.18}$$

Assume that a digital thermometer with a resolution of 1ºC has a residual error of ±0.5ºC and the resolution of the thermometer is called Δ, than the variance is

$$\sigma^2 = \frac{\Delta^2}{12} \tag{2.19}$$

Since the mean error is zero, the range of the error will be

$$\text{Range} = \pm \Delta /2 \text{ or } \pm\sqrt{3}\sigma \tag{2.20}$$

The rectangular distribution is generally used for upper and lower limits of the measurement.

2.6.5. Normal Distribution

The most important distribution is the normal distribution, also known as the Gaussian distribution [2]. It has the probability density function given below

$$p(x) = \frac{1}{\sqrt{2\pi}\sigma}\exp\left[\frac{-(x-\mu)^2}{2\sigma^2}\right] \tag{2.21}$$

In this equation, μ and σ are the mean and the standard deviation of the distribution. Below is a sample graph for a normal distribution figure 2.3 [2].

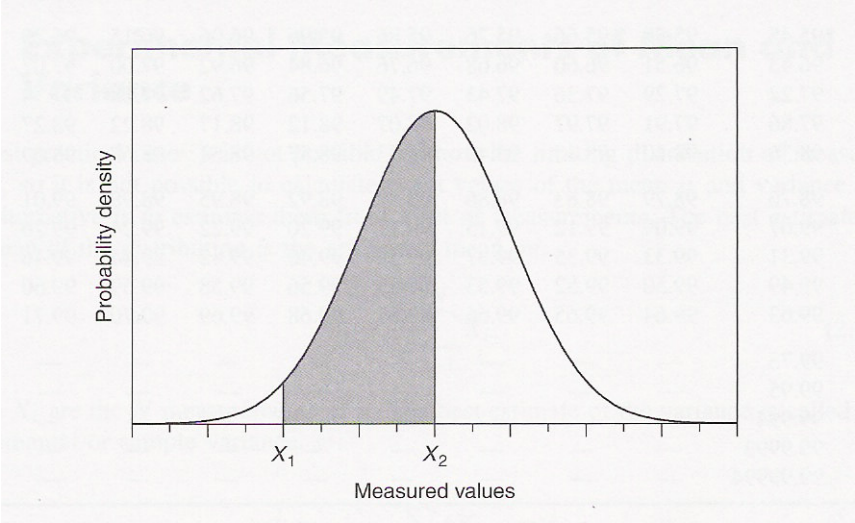


Figure 2.3 normal distribution

This distribution enables calculation of temperature fluctuations due to the turbulence in calibration baths or furnaces.

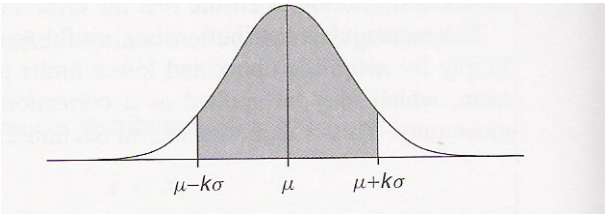


Figure 2.4 the percentage probability of finding x within $\mu \pm k\sigma$

. According to the graph above, when k = 1, 2, and 3, the measurement results lies within the range of:

k=1 ; 68.27 of measurements lie within ±1σ of the mean

k=2 ; 95.45 of measurements lie within ±2σ of the mean

k=3 ; 99.73 of measurements lie within ±3σ of the mean (2.22)

In real life, it is not possible to limit the distribution of measurements. To calculate values of the mean μ and variance σ^2 mathematical tools are used. To calculate the mean, arithmetic mean, m is used:

$$m = \frac{1}{N}\sum_{i=1}^{N} X_i, \tag{2.23}$$

where X_i and the N are measurements of x, and for variance, sample variance, s^2 is used:

$$s^2 = \frac{1}{N-1}\sum_{i=1}^{N} (X_i - m)^2, \tag{2.24}$$

where s is the experimental standard deviation. The Latin symbols are used for the equations of the experimental values and Greek symbols are used in theoretical equations. The graph below shows the differences between experimental and theoretical distributions figure 2.5 [2].

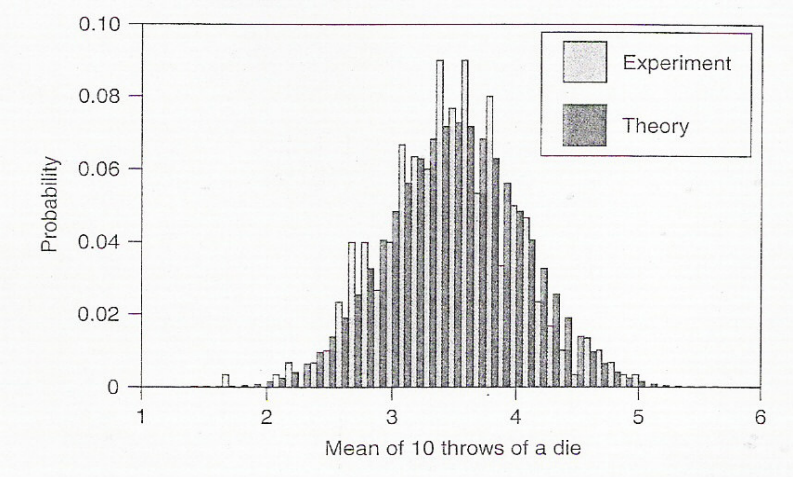


Figure 2.5 the differences between experimental and theoretical distributions

2.7. Evaluating Type A Uncertainties

To evaluate Type A uncertainties, the group is divided into two sections, one of which is single-valued and the other is distributed values. For single-valued uncertainties, the measurement can be reported as the mean with an uncertainty given by [2].

$$\text{Uncertainty} = S_m \tag{2.25}$$

Now the uncertainty is known as the standard uncertainty as the expression includes standard deviation, and generally, the expression one-sigma uncertainty is used in scientific literature. However, this standard deviation includes a range of only 68% of all measurements. To overcome this problem, expanded uncertainty must be defined.

$$\text{Uncertainty} = k \text{ x } S_m \tag{2.26}$$

k is the coverage factor that increases the range of the measurement. By taking $k = 2$, the included range will be ~ 95%.

For a calibration laboratory, single-valued uncertainty is well defined. However, when measuring the performance of measurement, devices outside the laboratory, the uncertainty is not single-valued but distributed. Distributed quantities depend generally on two basic factors: the mean correction and systematic errors. The sum of these two uncertainties leads to a standard uncertainty $(1+N)^{1/2}$ times larger than a single-valued quantity [2].

$$result = m \pm \left(1 + \frac{1}{N}\right)^{1/2} s. \tag{2.27}$$

with an expanded uncertainty reported as

$$result = m \pm k\left(1 + \frac{1}{N}\right)^{1/2} s. \tag{2.28}$$

2.8. Evaluating Type B Uncertainties

Type B uncertainties cannot be solved by statistical means. Type B uncertainties depend on the manuals of the measuring device, data sheets, calibration certificates, and even experience. There are several ways of overcoming the problem; including identification and recording of problems, theoretical evaluations, problems based on data from other sources, evaluations from secondary measurements and experience.

2.9. Combining Uncertainties

In real life, most of the measurements have more than one source of uncertainty. In a calibration laboratory, there is a reference thermometer, a calibration bath and a thermometer under the test. In order to find the overall uncertainty, it is necessary to combine all the uncertainties. Suppose the measurements are *u,v,w,x,…*

$$z = u+v+w+x+\ldots. \tag{2.29}$$

Assume that we know the mean and variance for each distribution

$$\mu_z = \mu_u+\mu_v+\mu_w+\mu_x+\ldots. \tag{2.30}$$

From distribution theory

$$\sigma_z^2 = \sigma_u^2 + \sigma_v^2 + \sigma_w^2 + \sigma_x^2 +\ldots. \tag{2.31}$$

Replacing the theoretical standard deviation with the experimental standard deviation solves the problem of how to combine standard uncertainties.

$$U_z = (k_u^2 s_u^2 + k_v^2 s_v^2 + k_w^2 s_w^2 + k_x^2 s_x^2 + \ldots)^{1/2} \tag{2.32}$$

where $k_u, k_v, \ldots$ all correspond to the same level of confidence.

$$U_z = k s_z \tag{2.33}$$

There is a better approximation known as the Welch-Satterthwaite equation

$$v_{eff} = s_z^4 \left[\frac{s_u^4}{v_u} + \frac{s_v^4}{v_u} + \frac{s_w^4}{v_w} + \frac{s_x^4}{v_x} + \ldots \right]^{-1}. \tag{2.34}$$

also can be written as

$$y=f(x_1,x_2,.....,x_n) \tag{2.35}$$

y is the combined standard uncertainty of measurement result, related to input values $x_1,x_2,...x_n$
is given by

$$U_c^2(y)=\left(\frac{\partial f}{\partial x_1}\right)^2 U^2(x_1)+\left(\frac{\partial f}{\partial x_2}\right)^2 U^2(x_2)+....+\left(\frac{\partial f}{\partial x_n}\right)^2 U^2(x_n) \tag{2.36}$$

where $U(x_1),U(x_2),\ldots U(x_n)$ are standard uncertainties evaluated . Equation (2.36) is valid only input quantities are independent. If the input quantities are correlated then covariances have to be taken

$$U_c^2(y)=\sum_{i=1}^{n}\left(\frac{\partial f}{\partial x_i}\right)^2 U^2(x_i)+2\sum_{i=1}^{n-1}\sum_{j=i+1}^{n}\left(\frac{\partial f}{\partial x_i}\right)\left(\frac{\partial f}{\partial x_j}\right)U(x_i-x_j) \tag{2.37}$$

in this equation the terms $U(x_i,x_j)$ are the coveariances of the input parameters x_i and x_j where $j=x_i+1$. Equation (2.37) is known as law of propagation of uncertainties. When the input quantities are independent the second term in equation (2.37) is zero and equation (2.36) results. Welch-Satterthwaite formula can be written like

$$v_{eff}=\frac{u_c^4(y)}{\sum_{i=1}^{n}\frac{u_i^4(y)}{v_i}} \tag{2.38}$$

where

$$U_i(y)=\left(\frac{\partial f}{\partial x_i}\right)U(x_i) \tag{2.39}$$

v_i = degrees of freedom of input uncertainty $U_i(y)$ [9].

2.10. Propagation of Uncertainty

Propagation of uncertainty requires some extra knowledge, usually a model of the measurement process. The propagation of uncertainty for a resistance thermometer is shown below.

$$R(t) = R_0(1+\alpha t), \tag{2.40}$$

where R_o is the basic value and á is the temperature coefficient

$$t = \frac{R(t) - R_0}{R_0 \alpha}\ , \tag{2.41}$$

Suppose there is a small error ΔR in the measurement R(t). This will give rise to a temperature measurement with an error by the amount

$$\Delta t = t_{means} - t_{true} = \frac{R(t) + \Delta R - R_0}{R_0 \alpha} - \frac{R(t) - R_0}{R_0 \alpha} = \frac{1}{R_0 \alpha}\Delta R \tag{2.42}$$

The propagation of uncertainty follows a similar equation

$$\sigma_t = \left(\frac{1}{R_0 \alpha}\right)\sigma_R \tag{2.43}$$

The term in the parenthesis is called the sensitivity coefficient. The general result for any function of independent random variables

$$z = f(x, y, ...)$$

$$\sigma_z^2 = \left(\frac{\partial f}{\partial x}\right)^2 \sigma_x^2 + \left(\frac{\partial f}{\partial y}\right)^2 \sigma_y^2 ... \tag{2.44}$$

This equation is known as the propagation of uncertainty, the terms in parenthesis are various sensitivity coefficients, the variables x, y are called input quantities, and z is called output quantity. To calculate a correlated uncertainty the equation below is used

$$\sigma_z^2 = \sum_{i=1}^{N}\left(\frac{\partial z}{\partial x_i}\right)^2 \sigma_{x_i}^2 + \sum_{i=1}^{N}\sum_{\substack{j=1 \\ j\neq 1}}^{N}\left(\frac{\partial z}{\partial x_i}\right)\left(\frac{\partial z}{\partial x_j}\right)\sigma_{x_i,x_j}, \tag{2.45}$$

where $\sigma_{x,y}$ is known as covariance. This is the most general form of the propagation of uncertainty formula. The covariance can be estimated from the measurement as

$$s_{y,x} = s_{x,y} = \frac{1}{N-1}\sum_{i=1}^{N}(X_i - m_x)\left(Y_i - m_y\right). \tag{2.46}$$

3. SENSORS

The electrical conductivity of metals depends on the movement of electrons in its crystal structure. According to the movement of electrons electrical resistance occurs. The electrical resistance of metals is very temperature dependent; the resistance increases with the temperature. The change in resistance R with respect to temperature, resented by the equation given below [10]:

$$R = R_0(1 + a_1T + a_2T^2 + ... + a_nT^n) \tag{3.1}$$

where R_0 is the resistance temperature at T=0, the number of terms depends on the material, the accuracy required and the temperature range to be covered. Materials most commonly used for resistance thermometers are platinum, copper and nickel. However platinum is the most commonly used metal. The indices change depending on the accuracy. Below the figure 3.1 shows temperature curves for nickel, copper and platinum.

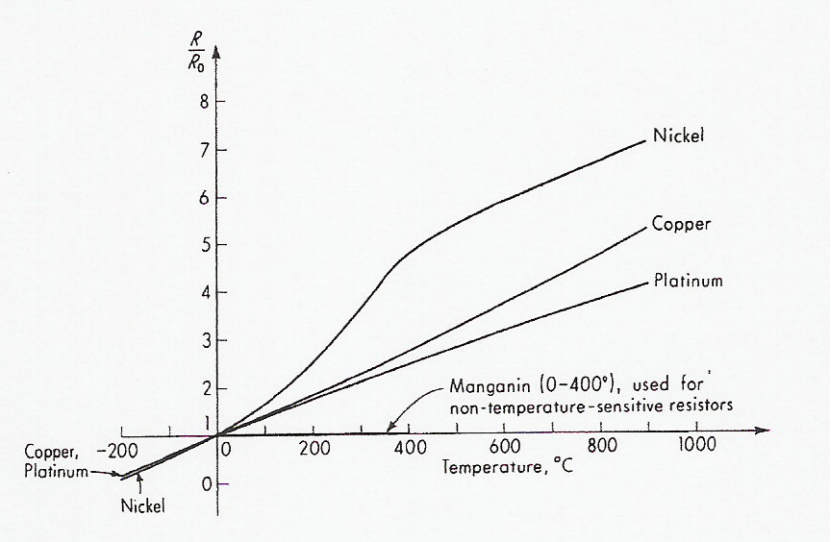


Figure 3.1 Resistance temperature curves

as seen in the figure Platinum has the most stable slope. Platinum is linear within ±0.4 percent over the ranges -184.44ºC to -73.33ºC and -73.33ºC to 148.88ºC, ±0.3 percent

from -17.77ºC to 148.88ºC ,±0.25 percent -184.44ºC to -128.88ºC, ±0.2 percent from -17.77ºC to 93.33ºC, and ±1.2 percent from 260ºC to 815.55.[10]. Standard platinum resistance thermometers are used between 13.8K and 962ºC to realize ITS-90 [10]. Platinum resistance thermometers use bridge circuits to minimize the deflection of the operation or invalid operation. There are many types of resistance thermometers. If the invalid method is used, resistor R_4, in figure 3.2 (a) is varied until the balance is formed. When the highest accuracy is required, the arrangement of figure 3.2(b) is preferred since the contact resistance in the adjustable resistor has no influence on the resistance of the bridge legs [10]. If long lead wires are subjected to the temperature variations are unavoidable, errors due to their resistance changes may be canceled by use of the Siemens three lead circuit of fig 3.2(c) [10].

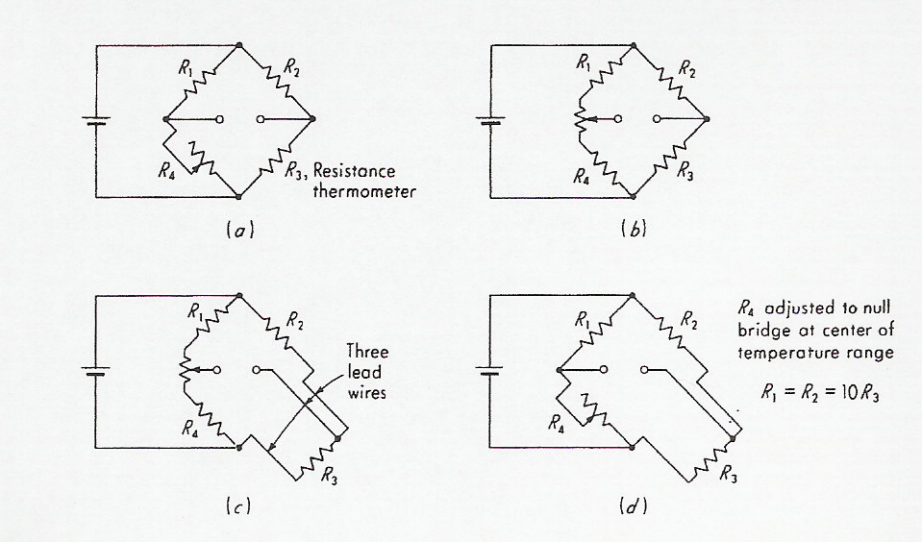


Figure 3.2 Resistance thermometer bridge circuits

for a bridge with four arms , fixed arms R_1 and R_2 have higher resistance than R_3 and R_4 the ratio is like (10:1) , by balancing the bridge at the middle of the temperature range, a good linearity will be obtained figure 3.2(d) . Resistance thermometer bridges can be excited with ac or dc voltages; generally, they use 2 to 20 mA current. These current causes an I^2R heating, which rises the temperature above its surroundings, is known as *self-heating*. The range of this error depends also on heat transfer conditions but this is a small kind of error. The bridge techniques are the classical methods for resistance thermometers,

however, four-wire ohmmeter can be used for better data linearization the figure 3.3 below there is an example of a four-wire ohmmeter[10]

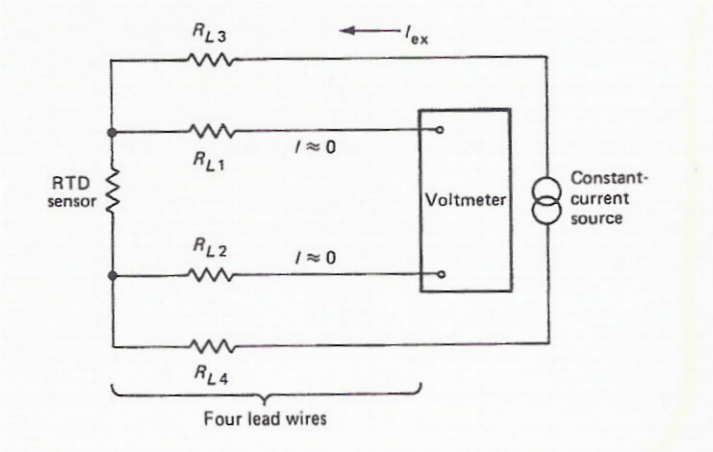


Figure 3.3 Four wire ohmmeter technique

the digital thermometers with four-wire sensor, nonlinearity is corrected by the software. Since a precise current source (usually a few miliamperes) is utilized, resistance changes in these two lead wires have no effect on sensor current, while high voltmeter input impedance (typically 200MÙ) makes current in its two lead wires negligible.[10]

4. TECHNICAL STRUCTURE

In this section, the preparation and the structure of the device will be explained. Under all the information given before, the mechanical, electronically, and metrological tools used will be discussed. The system depends on three main systems; are mechanical, electronic, and software. A basic scheme shows the steps in figure 4.1. The scheme will be explained in a appropriate order.

4.1 Construction of 3-D Temperature Scanner System

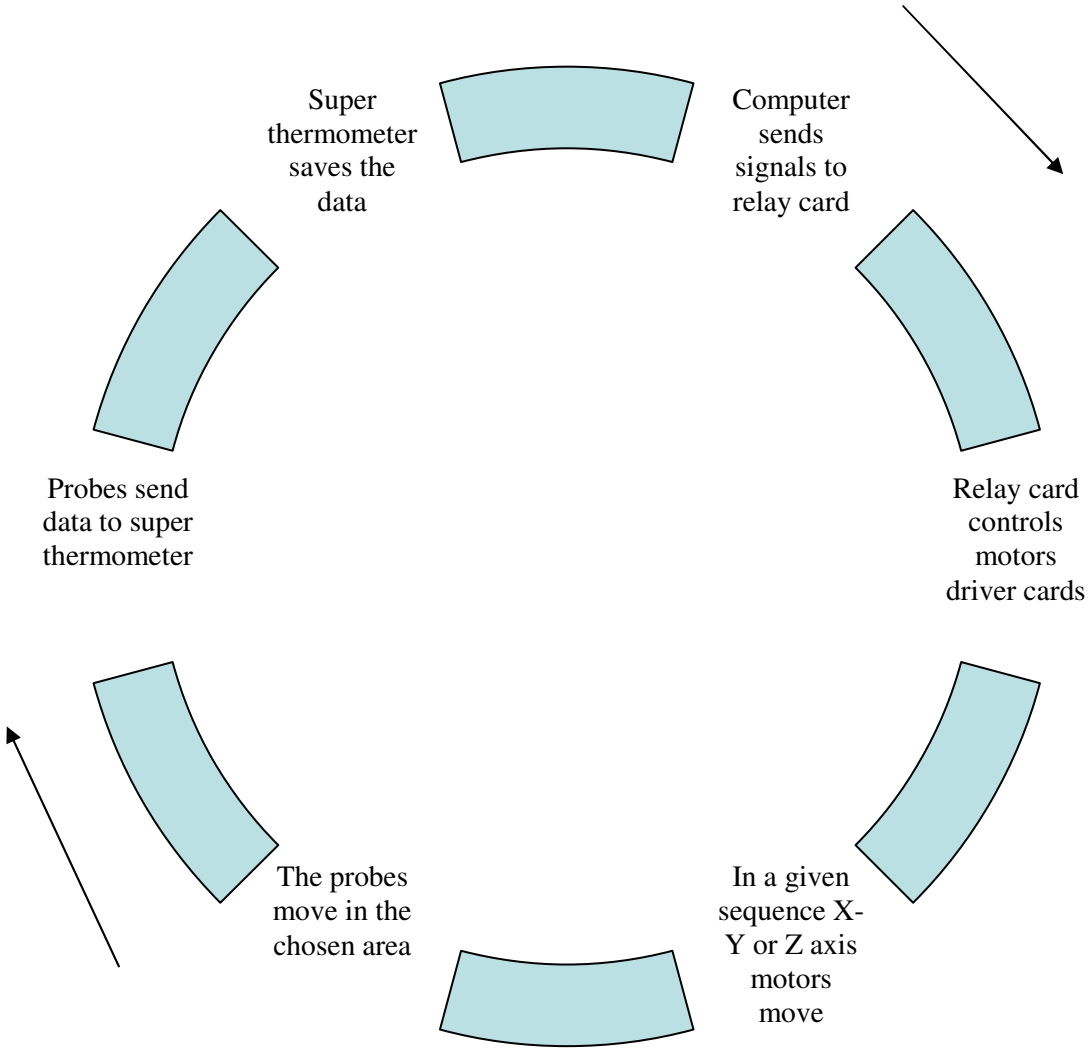


Figure 4.1 scheme of the system

4.2. Computer System

This is the first step for controlling the whole system. From the figure 4.1. The importance of the computer is the software that controls the relay card. The controlling relay card is the key point of the system, using this, the user has the ability to control all axes, moving times and stop times of the scanner. The program requires the entry values of time and coordinates to move the mechanical system in a logical routine way. For coordinates, the user must enter three values each for X, Y and Z directions and for timer settings, the user must enter two values for moving and for rest, after the values entered, the system starts with the command “BAŞLA”. For an emergency state there is a button labeled “duraklat” if the user presses this button, the whole system will pause except the super thermometer. There is also a button called “devam” if the user presses this button after “duraklat” the whole system will work from the point where it was stopped. It is shown in the figure 4.2 below

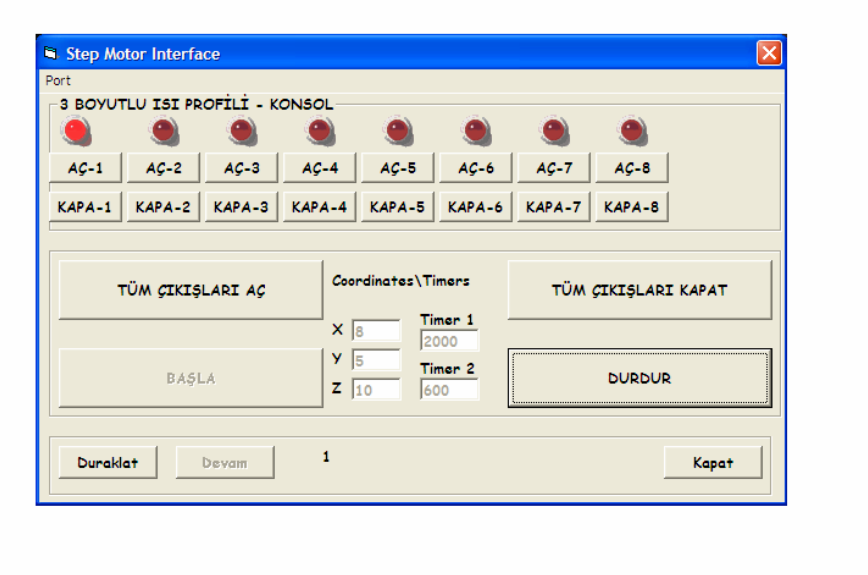


Figure 4.2 visual user interface of the software

The visual user interface (VUI) is shown above figure 4.2. After the “BAŞLA” command, the program opens and closes the relay card’s figure 4.4 gates in the order required. In the figure 4.2 there are buttons labeled “ac-1 to ac-8” and “kapa-1 to kapa-8” these are buttons for manual use, if the user requires the system to work in a different order; thus the system also be controlled manually. The Led’s above the buttons light up when a given button is

pressed to become active and turn off when the button is depressed and deactivated. The photograph as figure 4.3 given below is the relay card. The relay card takes its power independently from the computer shown in figure 4.18, its power source is a 12V DC current, and the relay card can control its gates up to 220V AC current. In this system, the card controls six 5V current and one 24V current with its gates. Utilizing this card the computer can control eight channels, but the system needs only seven of these and one gate remains unused in this condition.

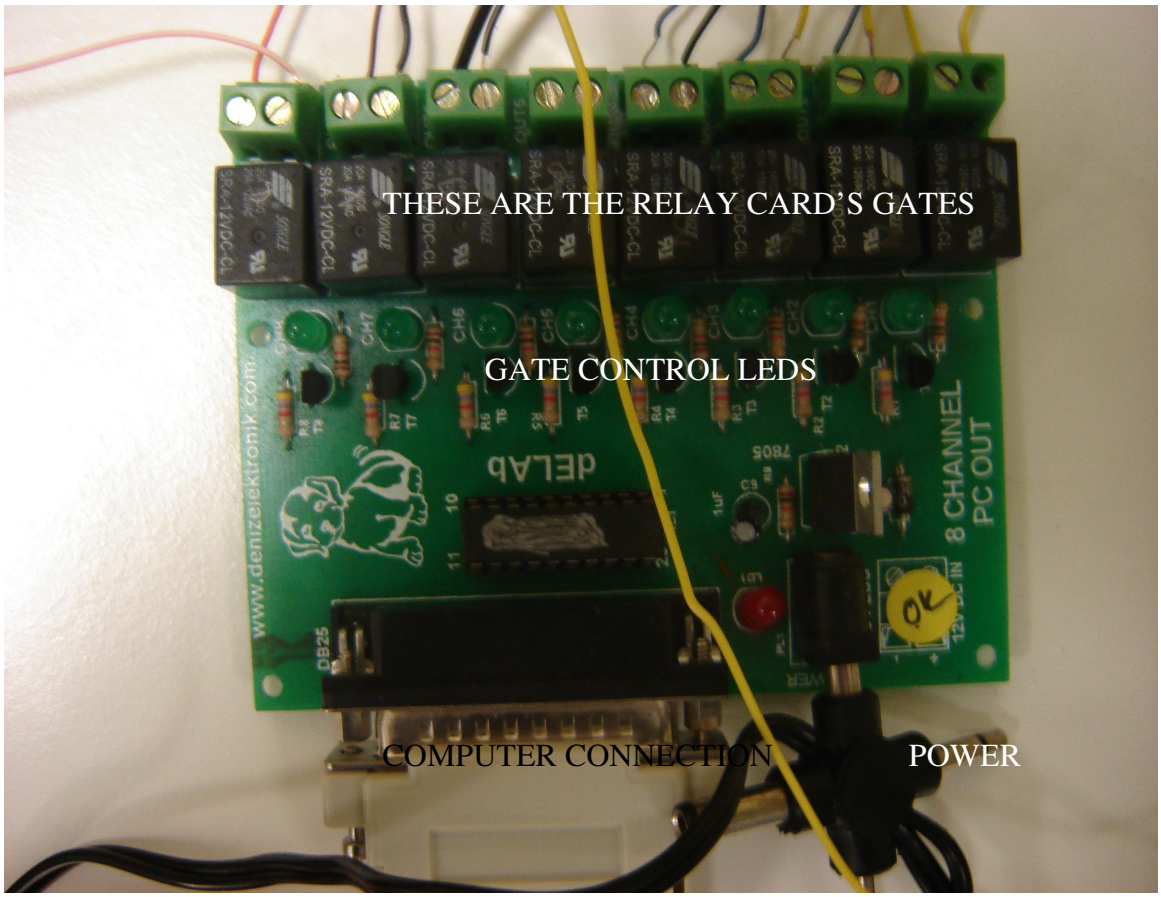


Figure 4.3 Picture of the relay card that is used

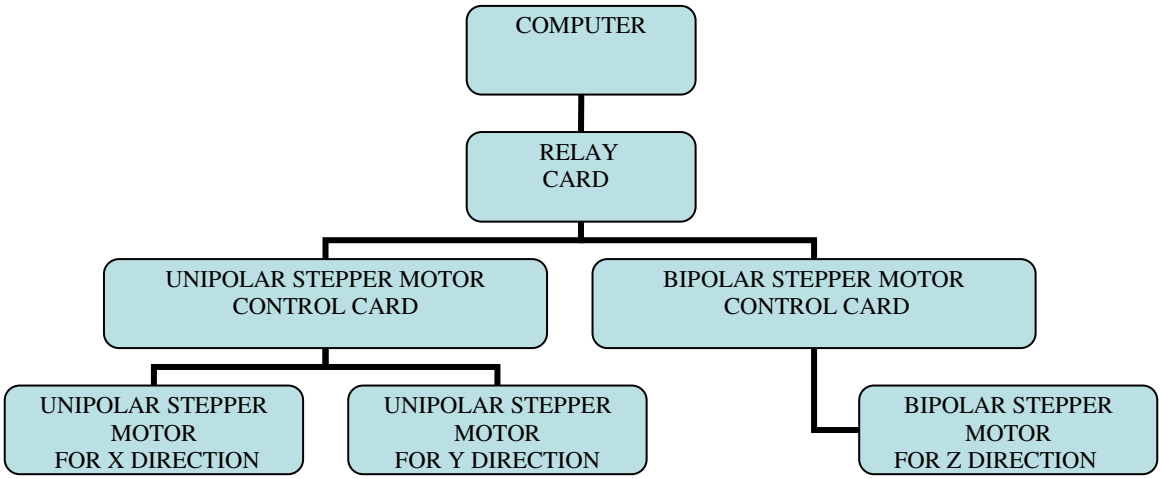


Figure 4.4 scheme shows the role of the computer and the relay card

after the relay card sends signals to the unipolar or bipolar motor control drive shown in figure 4.7 and figure 4.8 . The system has its other processor “figure 4.6” on the unipolar stepper motor control card and that scheme is below

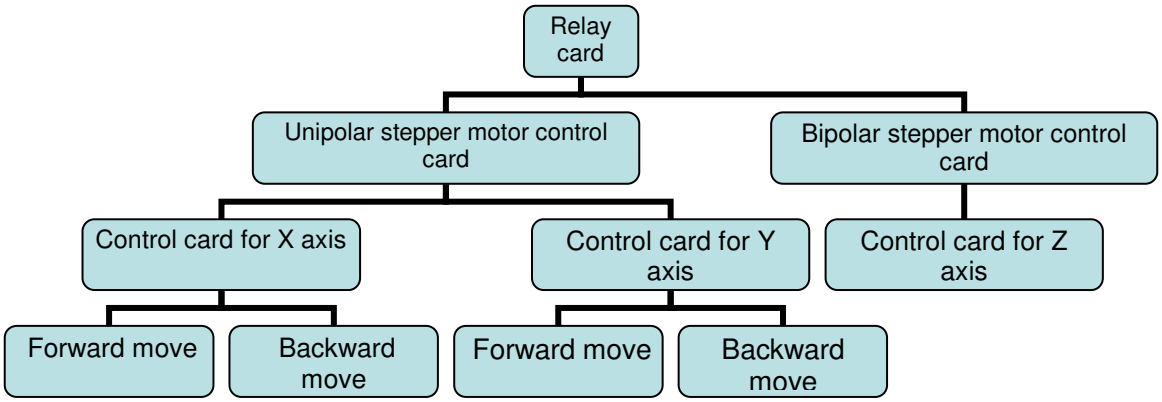


Figure 4.5 schemes of the relay card outputs

4.3. Unipolar Stepper Motor Control Card

This card has its own processor called PIC as seen in figure 4.6. There are four Pic16f84A micro controllers in the unipolar stepper motor control card shown in figure 4.7, each PIC unit has independent roles controlled by the relay card via the computer. Controller

PIC16f84 has a program memory (FLASH) - for storing a written program. Since memory made in FLASH technology can be programmed and cleared more than once, it makes this microcontroller suitable for device development, by using Ram memory, the PIC's in the system are programmed by the software given below. Using this program, the unipolar stepper motors are controlled by the PIC micro controllers. The Uln2003 chip receives the signals produced by the PIC micro controller and than unipolar stepper motors. The schemes above there are two main systems under the unipolar stepper motor controller card and each two have two subdivisions. Although the unipolar stepper motor controller card is a single card, it has two systems inside. One for the X-axis and the other for the Y-axis. Each axis has two PIC16f84A micro controllers for forward movement and backward movement.

Forward step:

```
#include <pic.h>
#include <delay.c>
main(void)
{
        unsigned char i ;
TRISA=0;
TRISB=0;
for(;;){
        RB4=1; RB7=1;
 DelayMs(250);
        RB4=0; RB7=0;
        RB4=1; RB5=1;
DelayMs(250);
        RB4=0; RB5=0;
        RB5=1; RB6=1;
 DelayMs(250);
        RB5=0; RB6=0;
        RB6=1; RB7=1;
DelayMs(250);
        RB6=0; RB7=0;
```

```
 }
}
```

Backward step:

```
#include <pic.h>
#include <delay.c>
main(void)
{
TRISA=0;
TRISB=0;
for(;;){
        RB7=1; RB4=1;
DelayMs(250);
        RB7=0; RB4=0;
        RB7=1; RB6=1;
DelayMs(250);
        RB7=0; RB6=0;
        RB6=1; RB5=1;
DelayMs(250);
        RB6=0; RB5=0;
        RB5=1; RB4=1;
DelayMs(250);
        RB5=0; RB4=0;


}
}
```

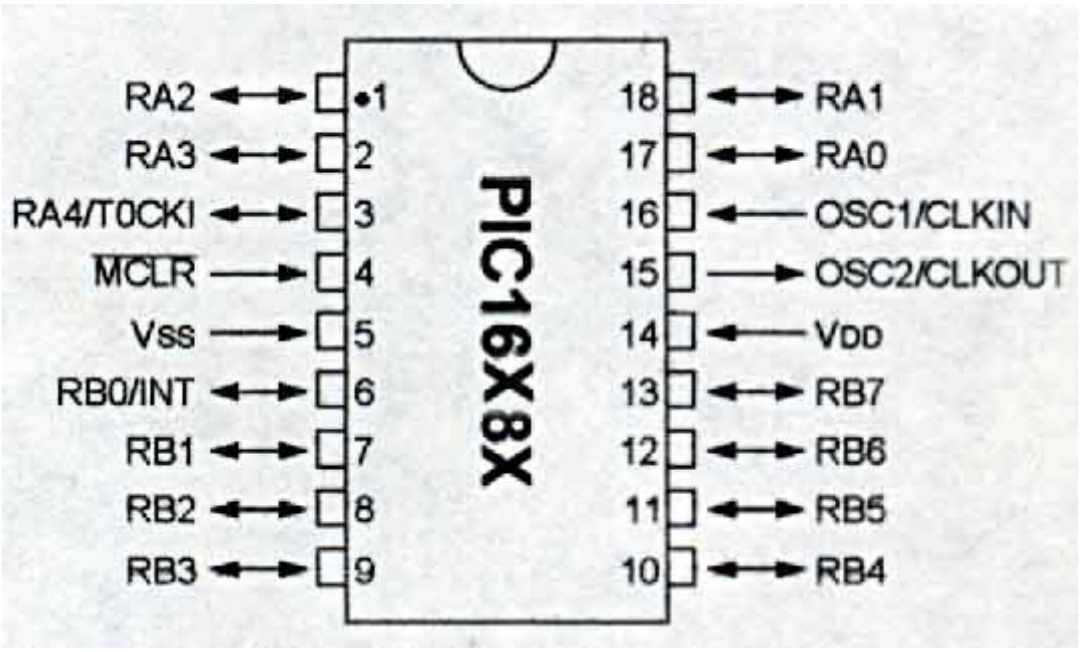


Figure 4.6 the structure of the PIC16F84A

RA0 To RA4:

RA is a bidirectional port. That is, it can be configured as an input or output. The number following RA is the bit number (0 to 4). So, there is one 5-bit directional port where each bit can be configured as either the Input or Output.

RB0 To RB7:

RB is a second bidirectional port. It behaves in exactly the same way as RA, except there are 8 - bits involved.

VSS And VDD:

These are the power supply pins. VDD is the positive supply, and VSS is the negative supply, or 0V. The maximum supply voltage that you can use is 6V, and the minimum is 2V

OSC1/CLK IN And OSC2/CLKOUT:

These pins are used to connect an external clock, so that the microcontroller has some kind of timing.

MCLR:

This pin is used to erase the memory locations inside the PIC (i.e. when it is required to re-program it). In normal use it is connected to the positive supply rail.

INT:

This is an input pin which can be monitored. If the pin goes high, the program can be restarted, stopped or any other single function required.

T0CK1:

This is another clock input, which operates an internal timer. It operates in isolation to the main clock.

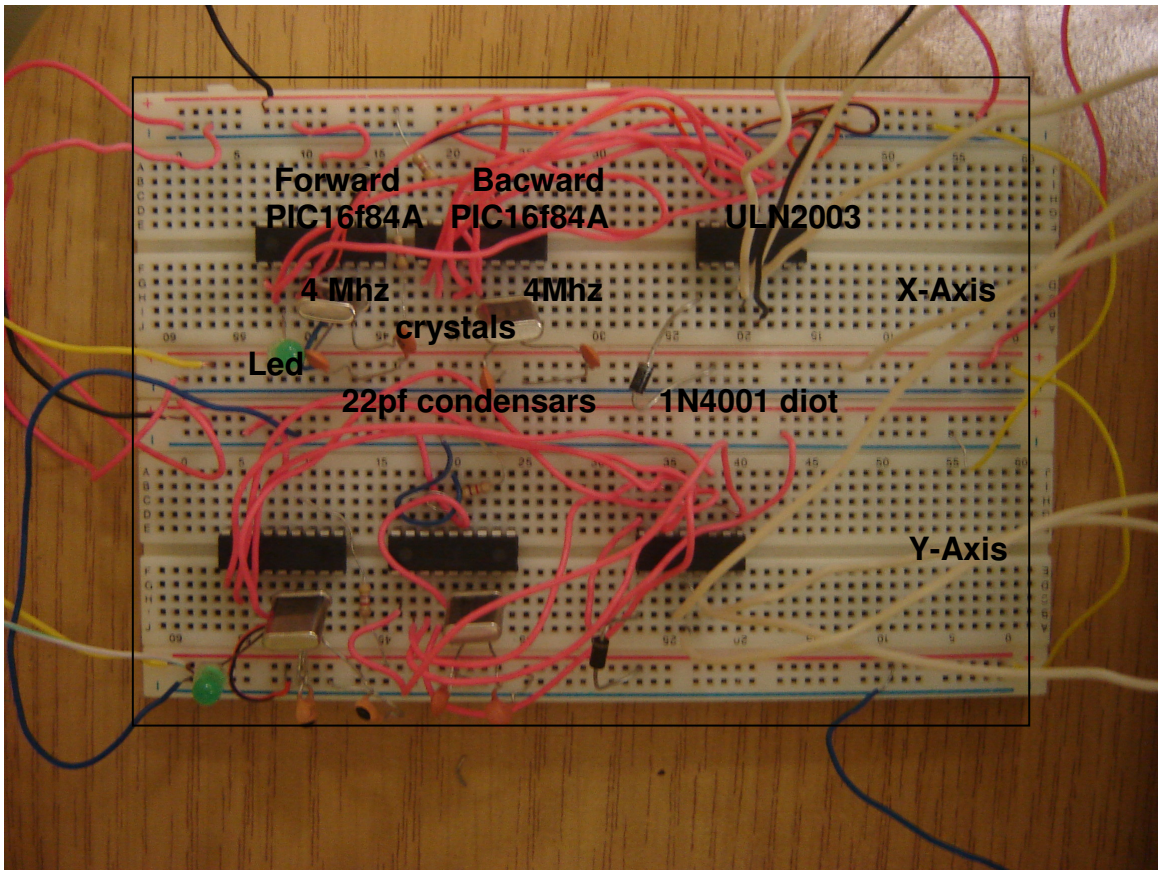


Figure 4.7 unipolar stepper motor controller card

The other part of the main branch after the relay card, is the bipolar stepper motor controller card and the bipolar stepper motor. The bipolar controller unit has two cards, the

driver card and the oscillation card. In the unipolar stepper motor controller card this oscillation is achieved with a 4 MHz crystal and the PIC16f84, however in the bipolar stepper motor there is another unit. A detailed photograph of a bipolar stepper motor control card is shown below; the signals from the relay card are received by this controller card, the main idea is the same, the relay card opens and closes the power of the controller card.

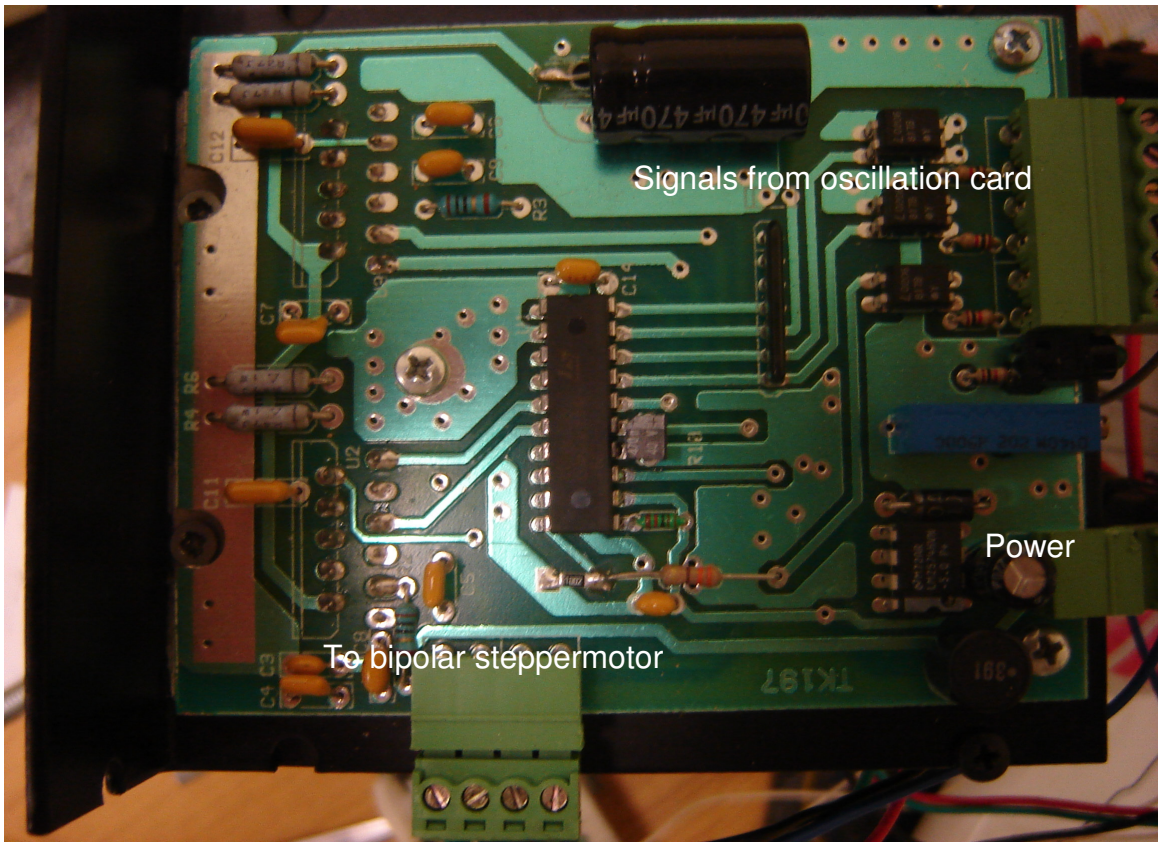


Figure 4.8 bipolar stepper motor controller card

4.4. Stepper motors:

The systems moving parts are controlled by stepper motors this is because of the stepper motors general structure. In DC motors, the users cannot control the exact start and stop times of the motor. DC motors have a gradual acceleration and deceleration curves, stabilization is slow, however adding some gears to a DC motor will help to reduce the problem. However, this is still a problem and precise start and stop values are not possible.

In this system, this problem is overcome by using stepper motors. The main reason for using stepper motors is that, stepper motors cannot run freely by themselves like DC motors, they move step by step at a given time interval. This is why they are called "stepper motor". Other characteristic differences with the DC motors are torque and speed relationships. DC motors cannot produce high torques at low speeds however, stepper motors can do this. A better description is that stepper motors produce higher torques at low speeds and can keep-up torque when they stationary. This is an important feature. The scanner system uses both of these features of stepper motors which since they are not possible with dc motors. The mechanical portion of the 3-D scanning system involves a Z-axis, which must be capable of being stationary during the sequence from the time it first moved. This can be easily performed by using the stepper motor. Stepper motors also have precise start and stop values, even when under acceptable forces. Stepper motors have windings inside which need to be energized in the correct sequence before the motor's shaft will rotate. Reversing the order of the sequence will cause the motor to rotate the other way. The two programs that were written in each PIC16f84A micro controller's RAM is for this reason. If the control signals are not sent in a proper way, the motor will not turn, tremble or buzz, or may be it will turn, but that will not be a systematically turn, it will be an unstable movement. Stepper motors usually have a voltage rating. This is specified in the motor's datasheet. Passing over the voltage limit a little is sometimes helpful to increase torque, but this will cause heating and shorten the life of the motor; exceeding the voltage rate will seriously damage the motor. The stepper motors' other general characteristics are resistance and degrees per step values. The resistance will determine the current drawn by the motor and affect the motor's torque and speed. Degrees per step is an important factor for the system chosen and the use of the stepper motor in the system. This factor specifies the number of degrees the shaft will rotate for each full step and it can be called the motor's resolution. In this system, both unipolar and bipolar motors have 1.8º degrees per step used.

4.5. Types of Stepper Motors

Stepper motors have two basic categories, permanent magnet and variable reluctance. The type of motor determines the type of drivers. In this system, permanent magnet stepper motors were used; two unipolar stepper motors and one bipolar stepper motor.

4.5.1. Unipolar Stepper Motors

Unipolar motors are relatively easy to control. A simple 1-of-'n' counter circuit can generate the proper stepping sequence, and drivers as simple as one transistor per winding are possible with unipolar motors figure 4.13-4.17. Unipolar stepper motors are characterized by their center-tapped windings. A common wiring scheme figure 4.9 [11] is to take all the taps of the center-tapped windings and feed them +MV (Motor voltage). The driver circuit would then ground each winding to energize it.

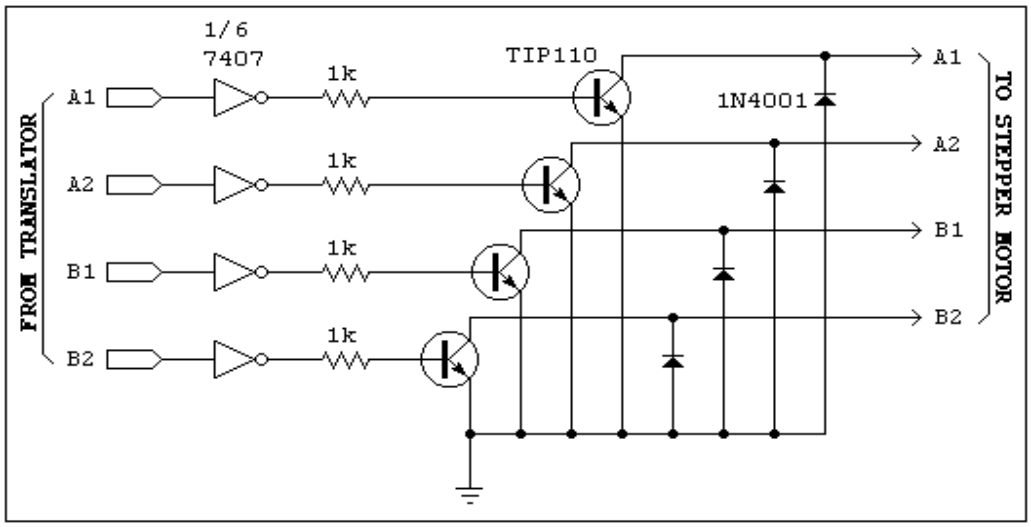
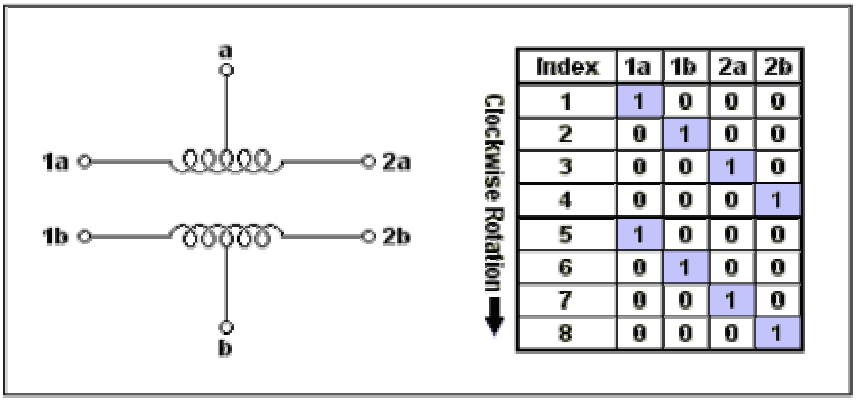


Figure 4.9 scheme of the stepper motor wiring

Unipolar stepper motors are recognized by their center-tapped windings. The number of phases is twice the number of coils, since each coil is divided in two. So the diagram below figure 4.10 [11], which has two center-tapped coils, represents the connection of a 4-phase unipolar stepper motor.



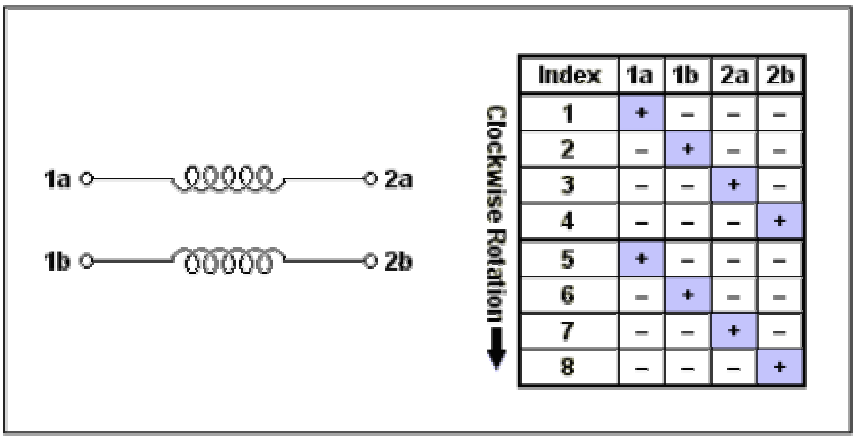
Index	1a	1b	2a	2b
1	1	0	0	0
2	0	1	0	0
3	0	0	1	0
4	0	0	0	1
5	1	0	0	0
6	0	1	0	0
7	0	0	1	0
8	0	0	0	1

Figure 4.10 connection of a 4-phase unipolar stepper motor.

In addition to the standard drive sequence, high-torque and half-step drive sequences are also possible. In the high-torque sequence, two windings are active at a time for each motor step. This two-winding combination yields around 1.5 times more torque than the standard sequence, but it draws twice the current. Half-stepping is achieved by combining the two sequences. First, one of the windings is activated, then two, then one, etc. This effectively doubles the number of steps the motor will advance for each revolution of the shaft, and it cuts the number of degrees per step.

4.5.2. Bipolar Stepper Motors

Unlike unipolar stepper motors, Bipolar units require more complex driver circuitry. Bipolar motors shown in figure 4.12 are known for their excellent size/torque ratio, and provide more torque for their size than unipolar motors. Bipolar motors are designed with separate coils that need to be driven in either direction (the polarity needs to be reversed during operation) for proper stepping to occur. This presents a driver challenge. Bipolar stepper motors use the same binary drive pattern as a unipolar motor, only the '0' and '1' signals correspond to the polarity of the voltage applied to the coils, not simply 'on-off' signals. The Figure 4.11 [11] below shows a basic 4-phase bipolar motor's coil setup and drive sequence.



Index	1a	1b	2a	2b
1	+	–	–	–
2	–	+	–	–
3	–	–	+	–
4	–	–	–	+
5	+	–	–	–
6	–	+	–	–
7	–	–	+	–
8	–	–	–	+

Figure 4.11 basic 4-phase bipolar motor's coil setup and drive sequence

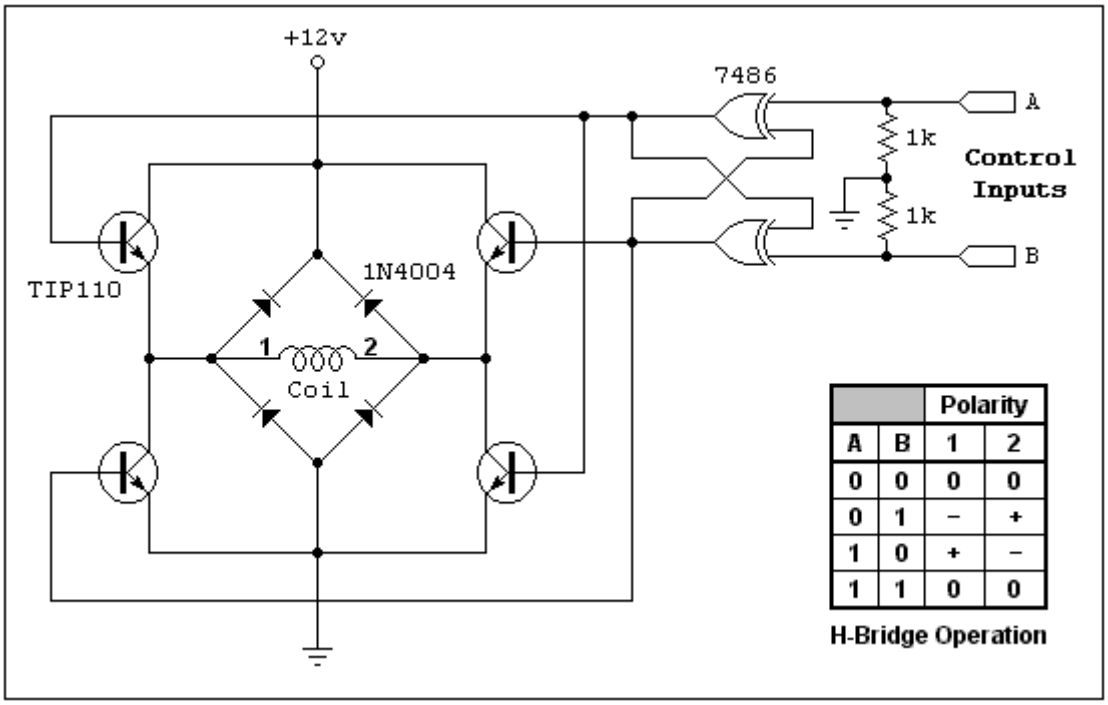


Figure 4.11a H-bridge circuit for bipolar stepper motors

A circuit known as an "H-bridge" figure 4.11a shown above is used to drive bipolar stepper motors[11]. Each coil of the stepper motor needs its own H-bridge driver circuit. Typical bipolar steppers have 4 leads, connected to two isolated coils in the motor. Chips are specifically designed to drive bipolar steppers are L297/298 series from ST Microelectronics which was used in the bipolar stepper motor controller card. The difference between unipolar and bipolar stepper motor is, a unipolar stepping motor has 5 or 6 lead wires usually with a center tap on each of two windings. In use, the center tap of the windings are typically wired to the positive supply, and the two ends of each winding are alternately grounded to reverse the direction of the field provided by that winding. However, a bipolar motor is constructed with exactly the same mechanism as is used on unipolar motors, the two windings are wired more simply, with no center tap. Thus, the motor itself is simpler but the drive circuitry needed to reverse the polarity of each pair of motor poles is more complex.

Stepper motors used for the system

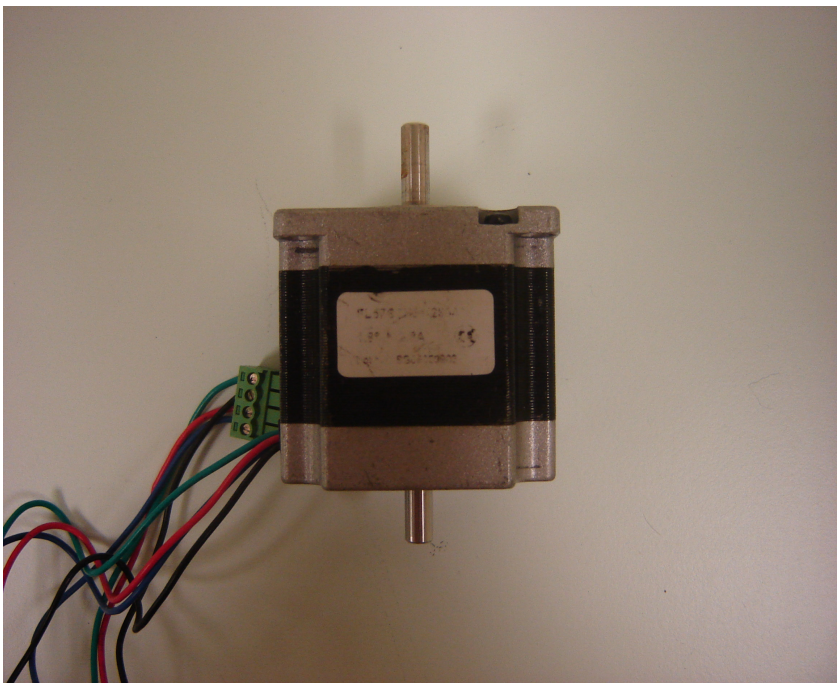


Figure 4.12 photograph of the bipolar stepper motor

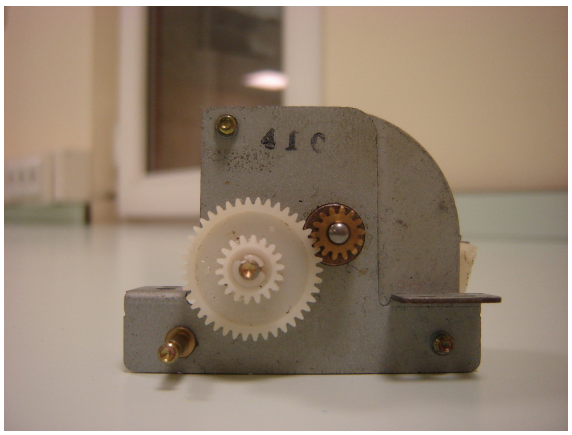


Figure 4.13 front view of unipolar stepper motor

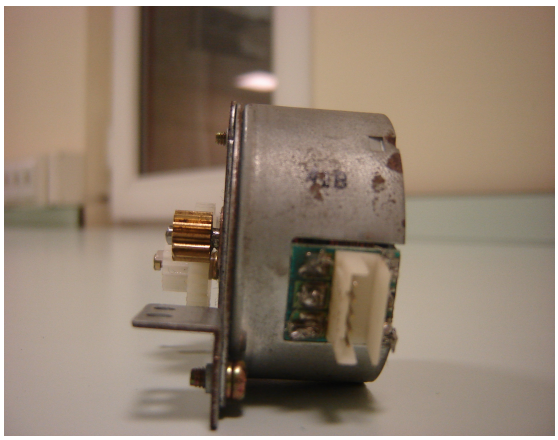


Figure 4.14 side view of unipolar stepper motor

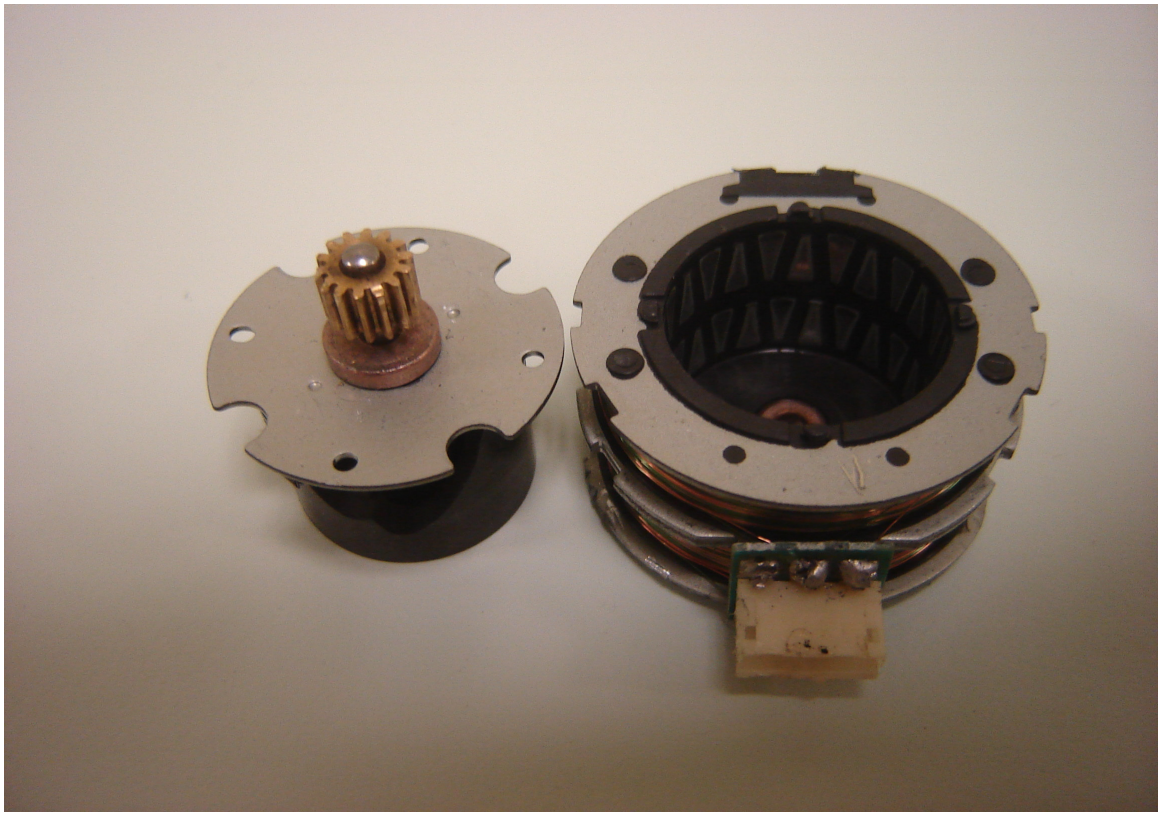


Figure 4.15 inside the unipolar stepper motor

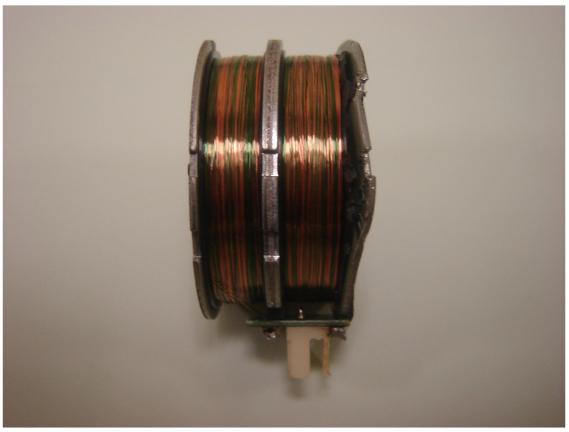


Figure 4.16 unipolar stepper motor coils

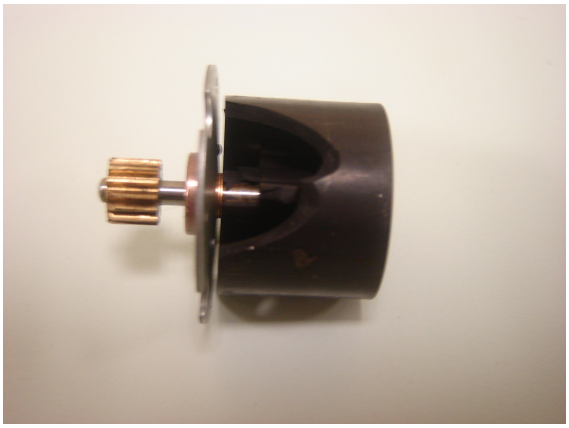


Figure 4.17 unipolar stepper motor magnet

Above, detailed pictures are taken from the inside of the unipolar stepper motor. In these figures the magnet winding and shaft can be seen in order.

The whole system uses three kind of power systems one 24V DC, one 12V DC and at last 5V DC. The 24V and 12V power system is for the bipolar and unipolar stepper motors, the 5V DC power system is for the PIC micro controllers. The relay card also works with 12V DC

Figure 4.18 photograph of the power supplies from left to right 24V DC, 5V DC and 12V DC power supply

4.6. Metal Construction

3-D Temperature Scanner's metal skeleton is formed by equipment that is low cost can be obtained easily. The materials are two drawer rails, one cornice, one iron tendon, three metric10 screws and some connecting parts. The detailed technical drawings are given below the units. The technical drawings are given in centimeters (cm.). Figures 4.19-4.26 shows the 3-D scanner systems skeleton.

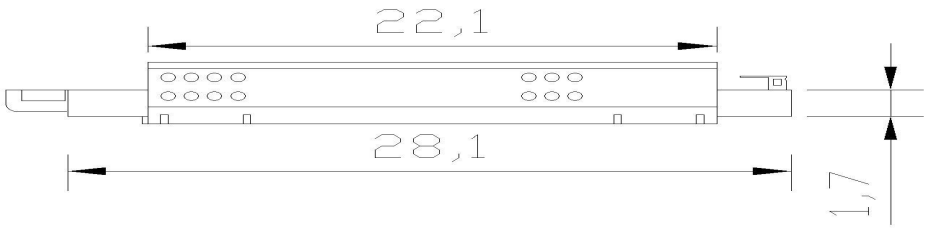


Figure 4.19 technical drawing of the moving tendon

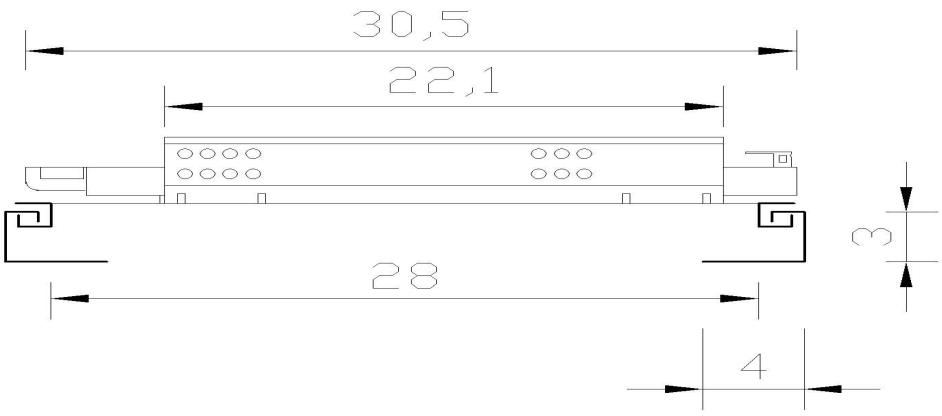


Figure 4.20 back view of the tendon placed on the sides

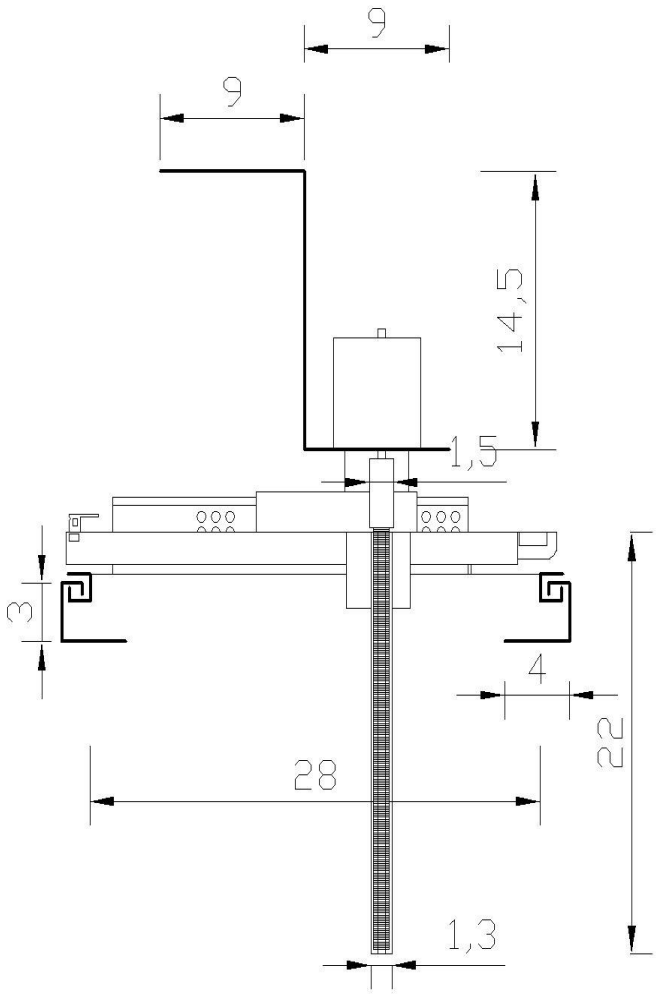


Figure 4.21a front view of the whole mechanical system

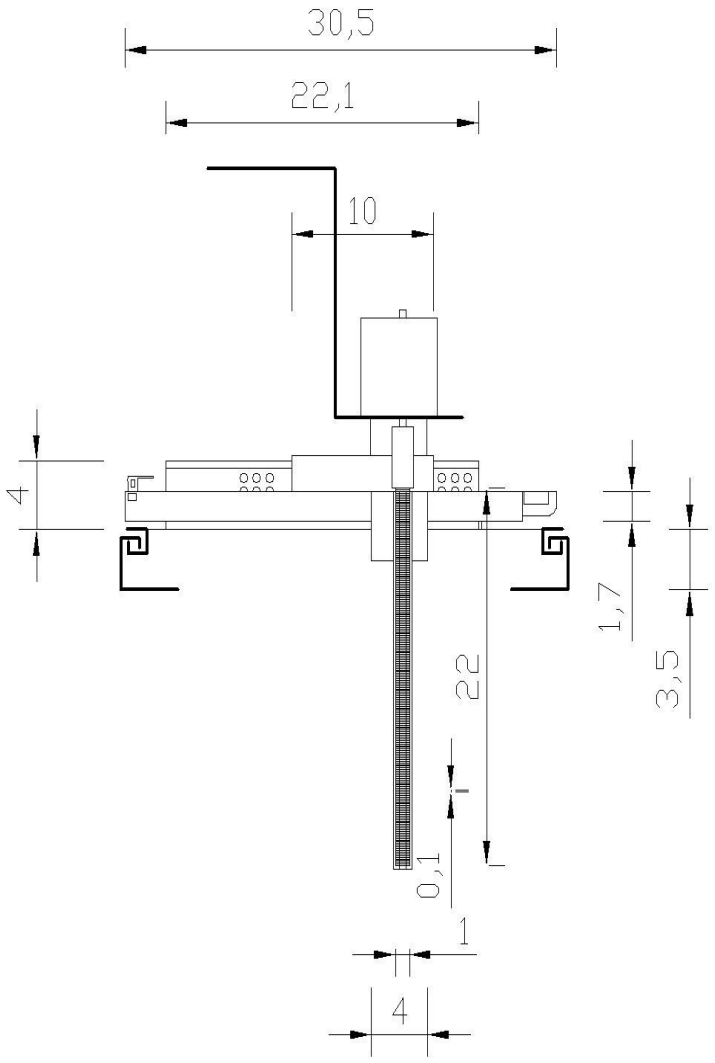
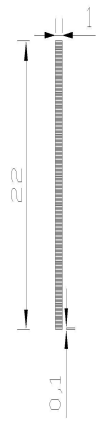


Figure 4.21b front view of the whole system



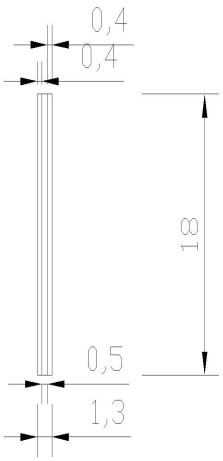


Figure 4.22 metric 10 screw

Figure 4.23 the cornice

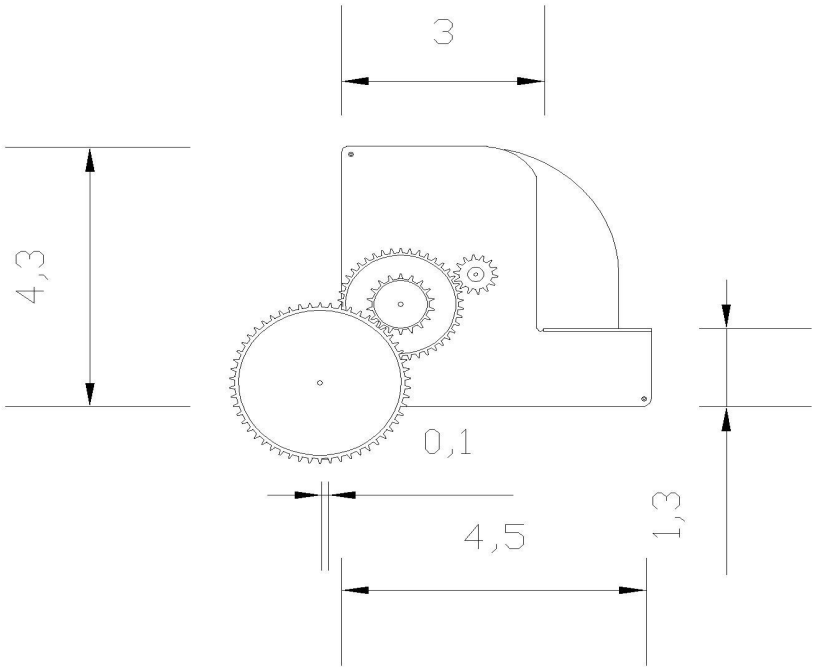


Figure 4.24 one of the unipolar stepper motor used for X and Y axis

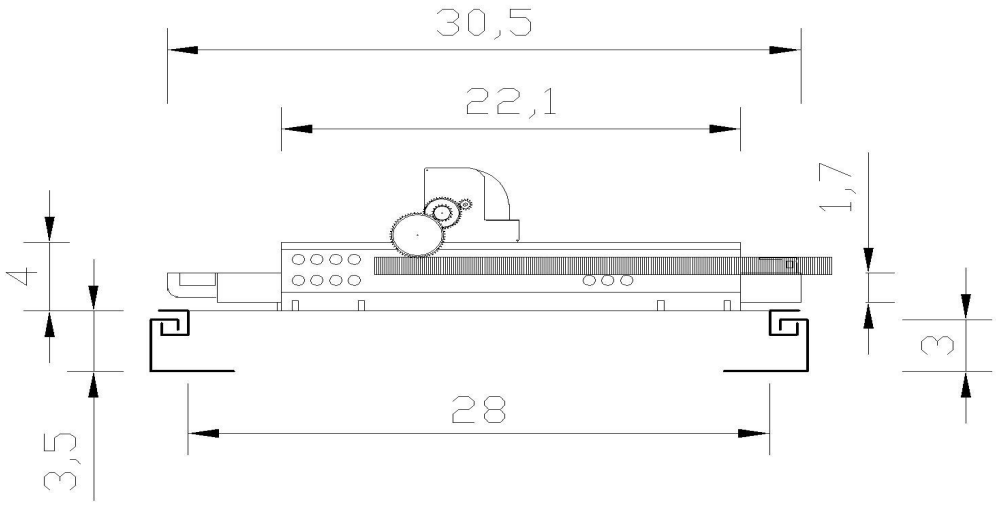


Figure 4 25 unipolar stepper motor placed on the tendon for x axis

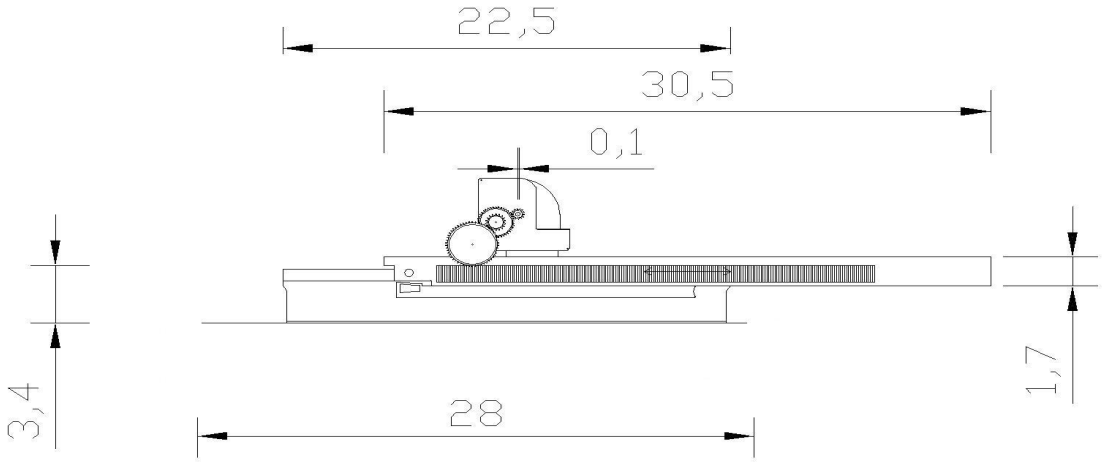


Figure 4.26 unipolar stepper motor placed on the side for y axis

Figure 4.27 photograph of the whole system

In Figure 4.27 experimental setup is shown from left to right A-the computer that is used for controlling software, B-the super thermometer and the bridge, E-water bath, on the water bath C-the 3-D mechanical system, in front of the water bath D-power supplies

5. RESULTS AND DISCUSSION

After all the detailed information about scanner system, the data that are collected from the water, oil and salt bath, using the scanner system, can be shown by using graphs. Before listing all the graphs, some information must be given about the baths (water-oil), like where the heater and propellers for homogeneity placed in. Picture is taken from the Hart Scientific publications [12].

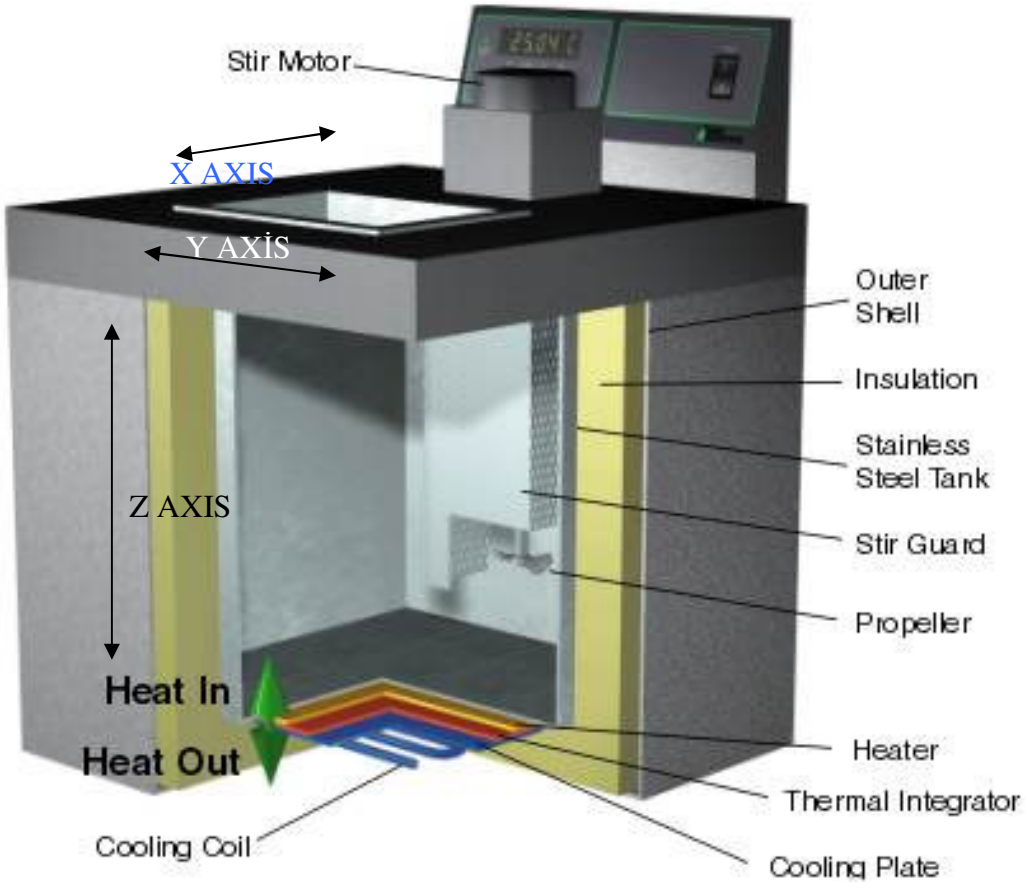


Figure 5.1 schematic diagram of the baths and the position of the scanner system

The scanner system starts from $(X_1,Y_{1)}$ moves to $(X_8,Y_{1)}$ than moves (Y_2,X_8) to (Y_2,X_1). After all the first layer completed at the point (X_1,Y_{10}), it immerse one step to (X_1,Y_{10},Z_1) point, and scans the bath by the given range.

5.1. Water Bath Results

To scan water bath the x, y, z values are X=8, Y=10 and Z=11. Intervals between integers are 1.5 cm. X, Y, Z-axes are 3-D dimensions, and the color is the fourth dimension depends on the temperature and its unit is Celsius.

Water Bath at 30ºC

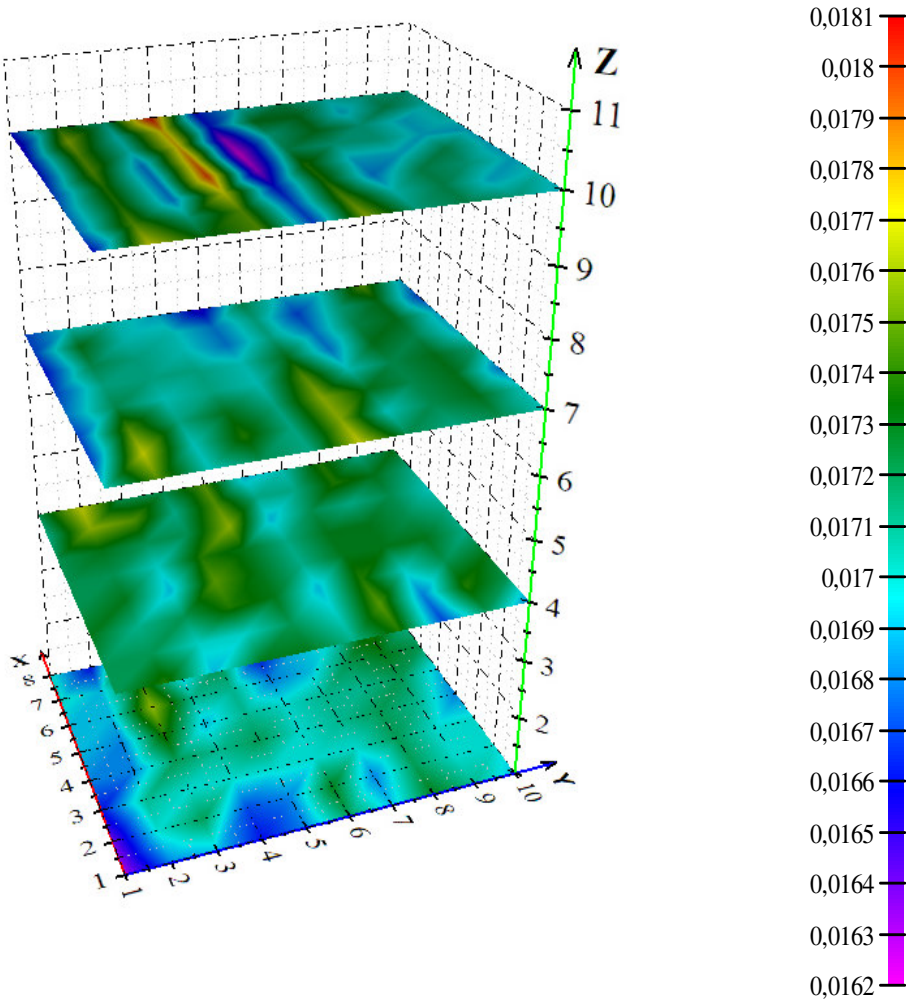


Figure 5.2 shows every third layer of the water bath at 30ºC

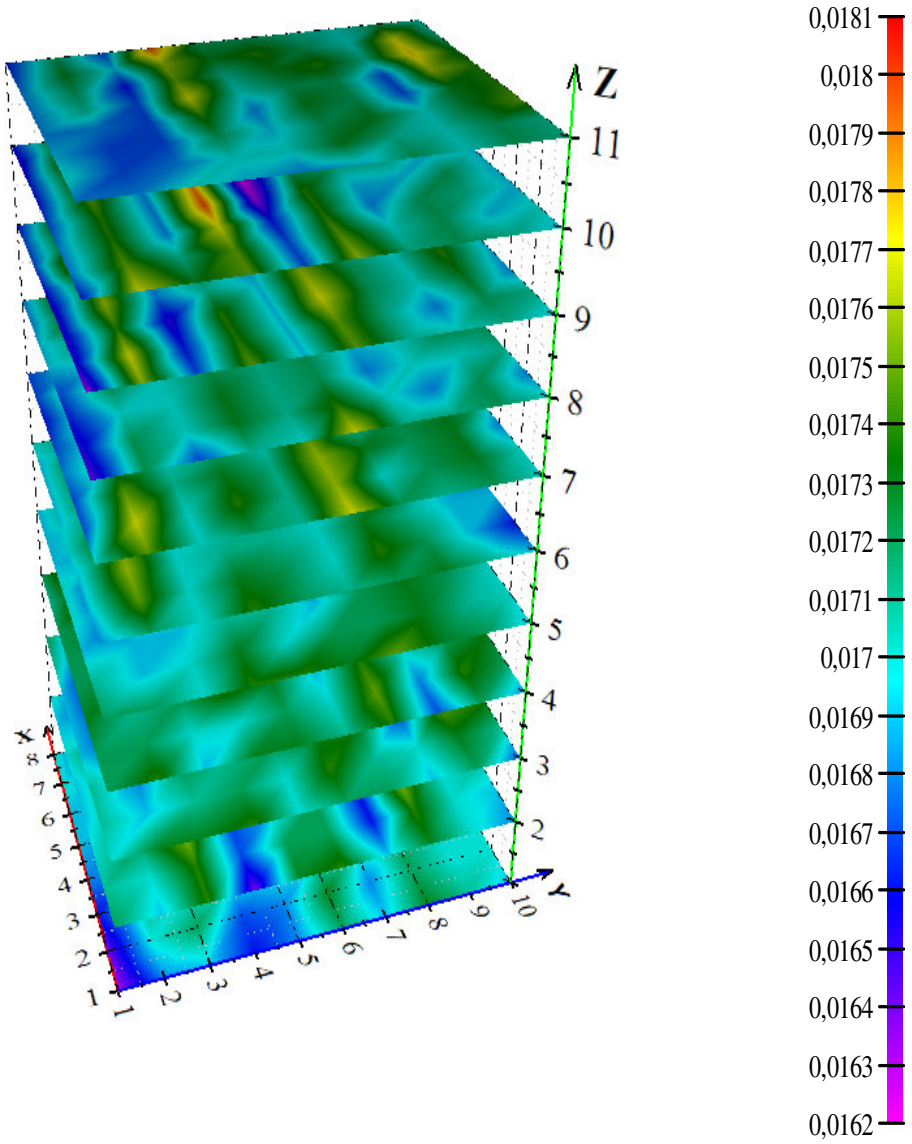


Figure 5.3 shows the full 11 layers of the water bath at 30ºC

Water Bath at 40ºC

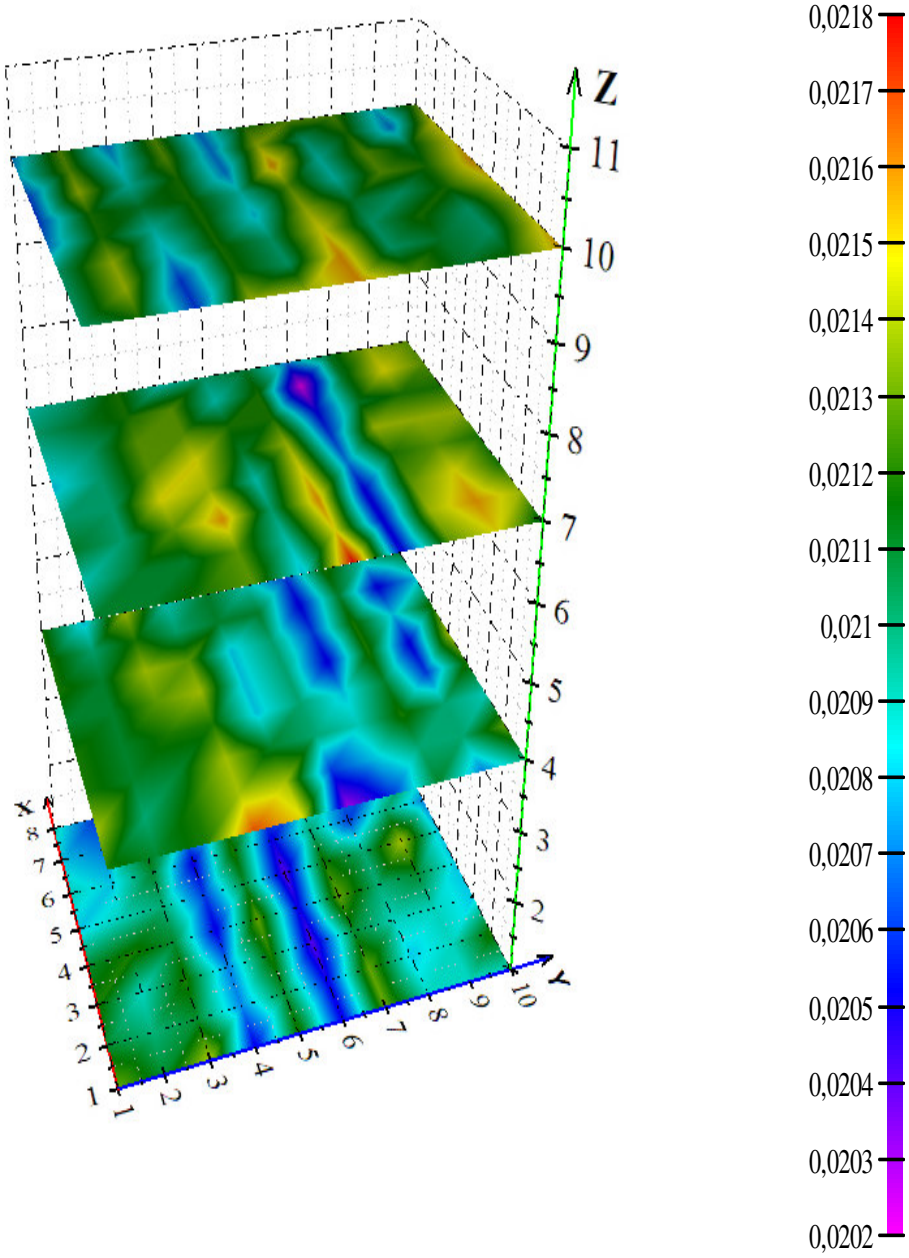


Figure 5.4 shows every third layer of the water bath at 40ºC

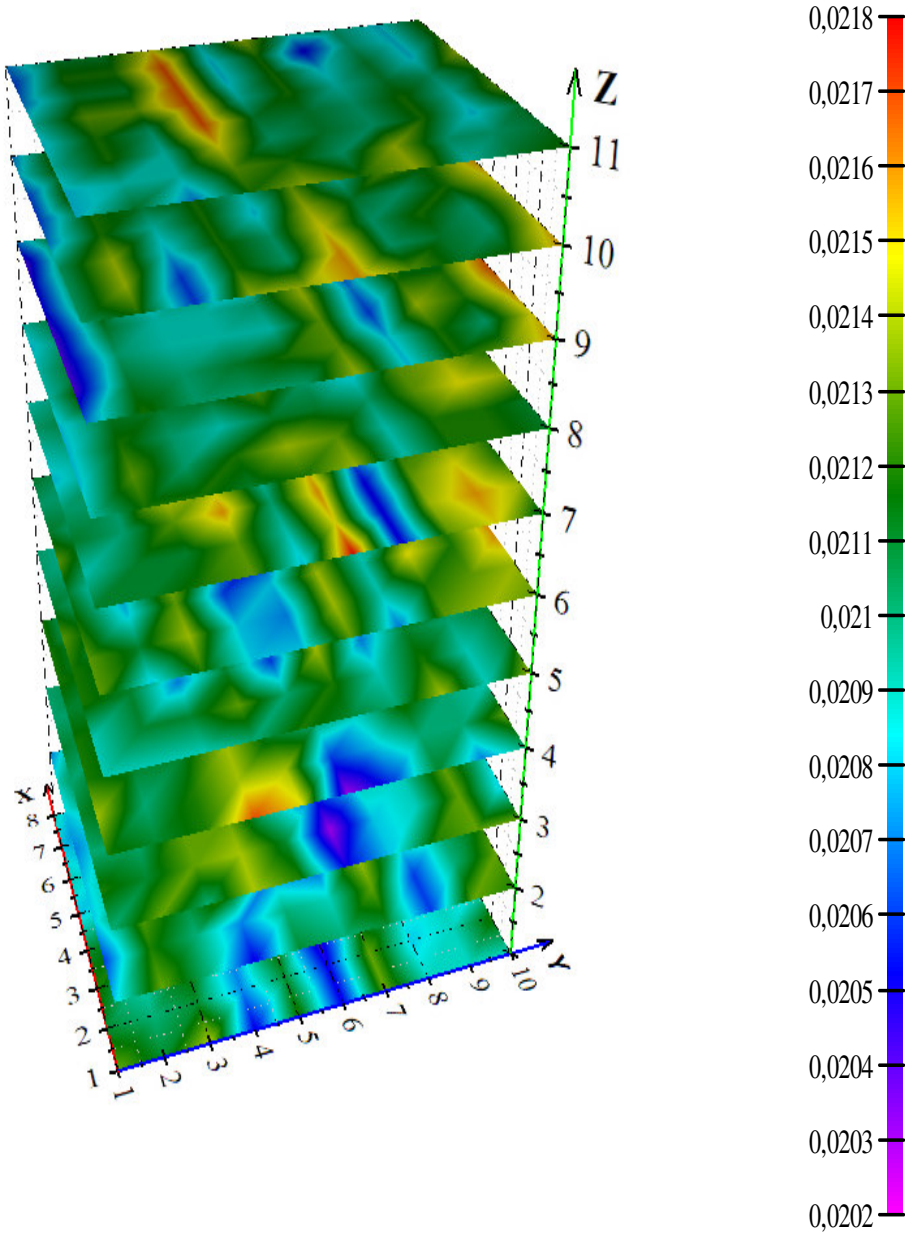


Figure 5.5 shows the full 11 layers of the water bath at 40ºC

Water bath at 50ºC

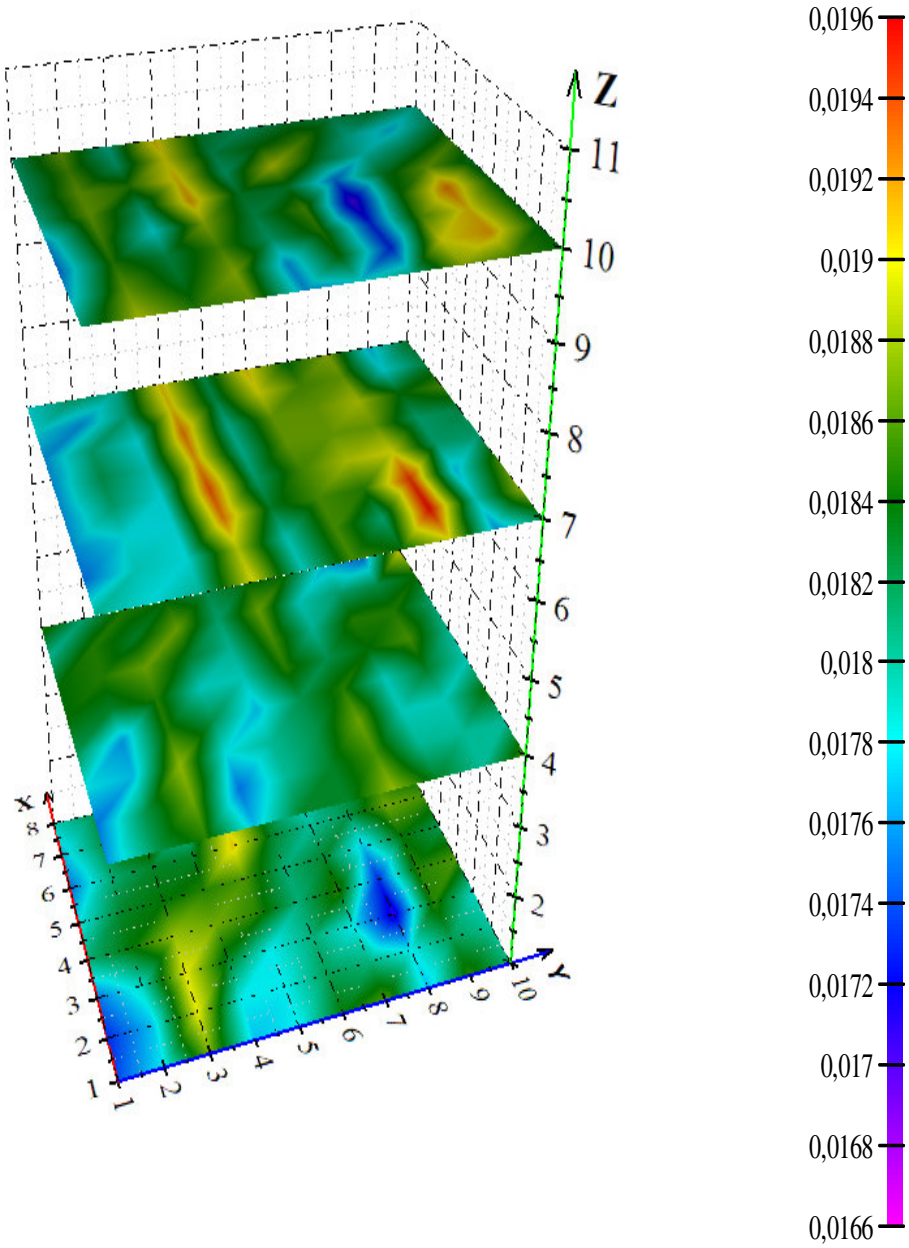


Figure 5.6 shows every third layer of the water bath at 50ºC

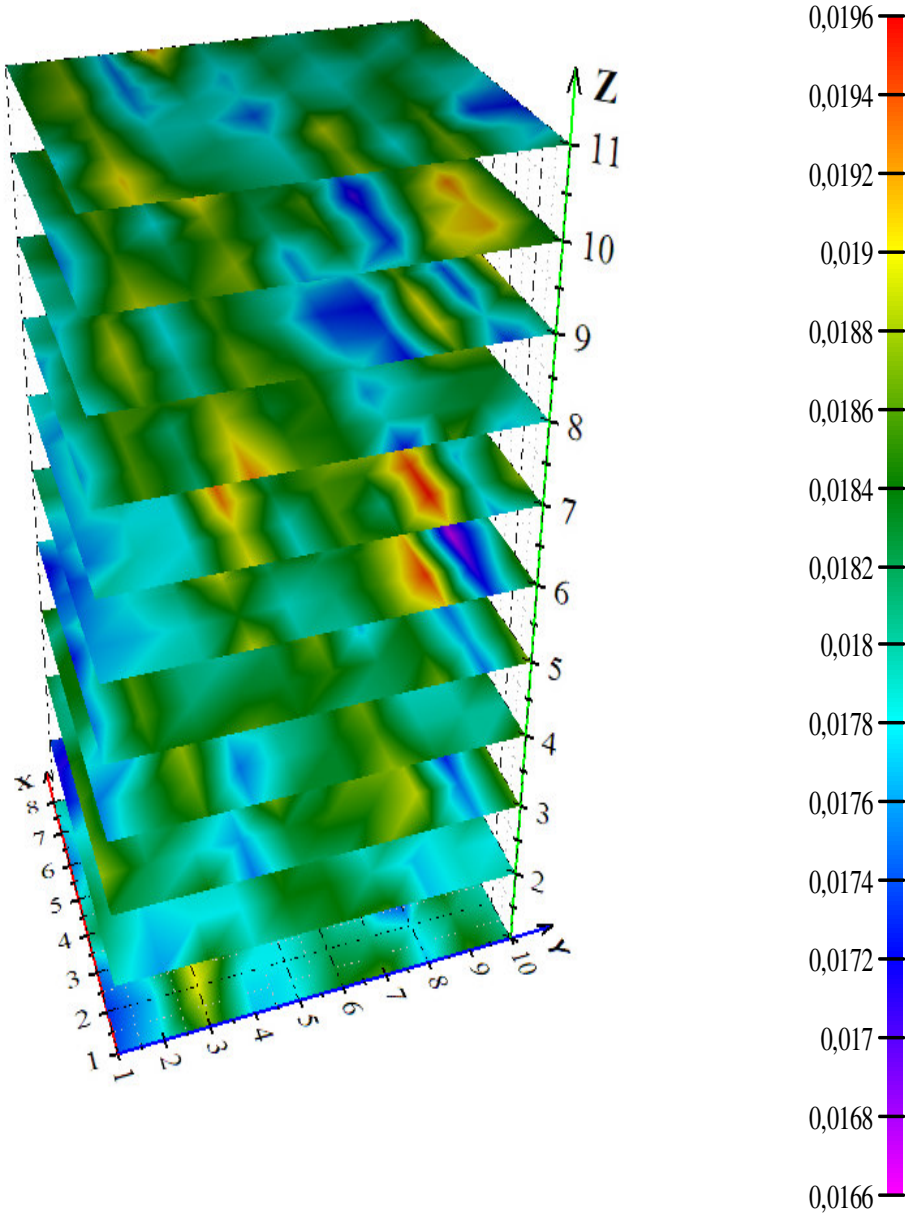


Figure 5.7 shows the full 11 layers of the water bath at 50ºC

Water Bath at 60ºC

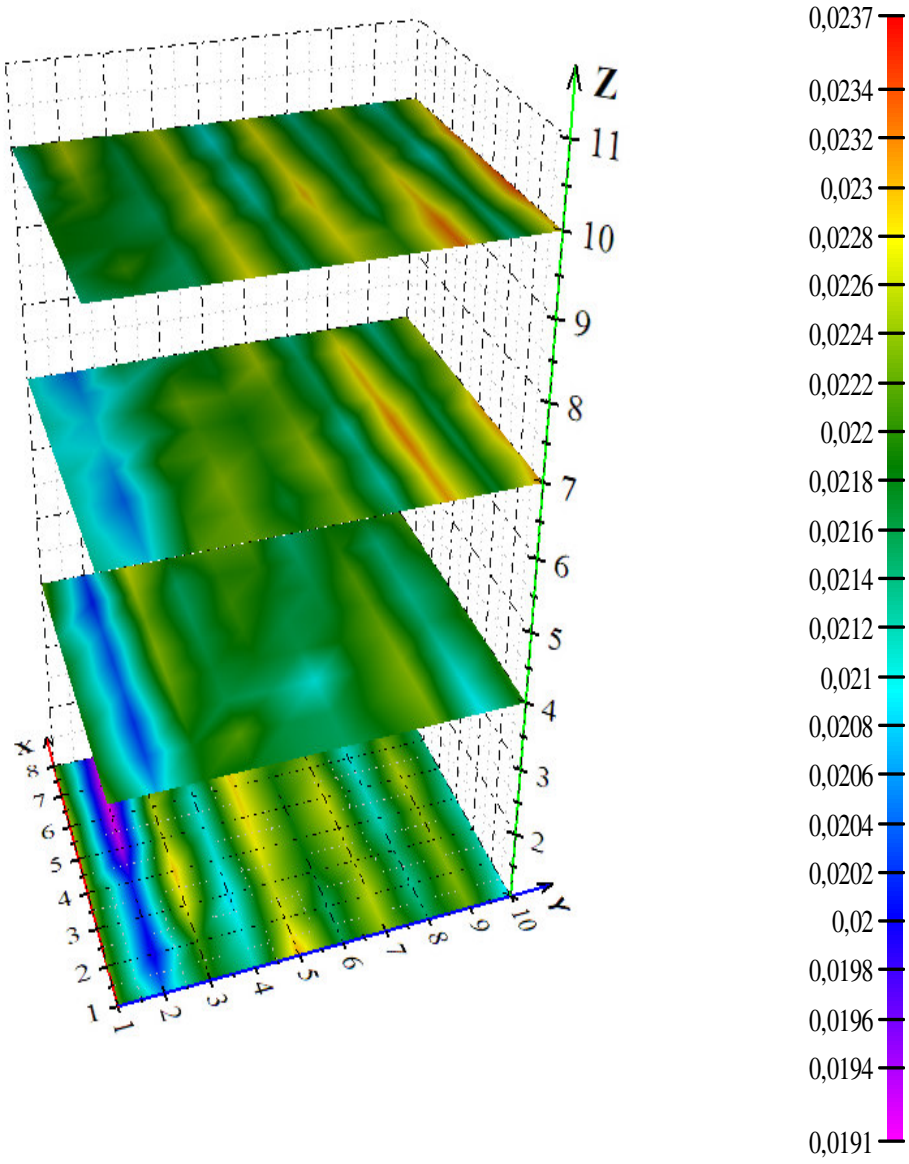


Figure 5.8 shows every third layer of the water bath at 60ºC

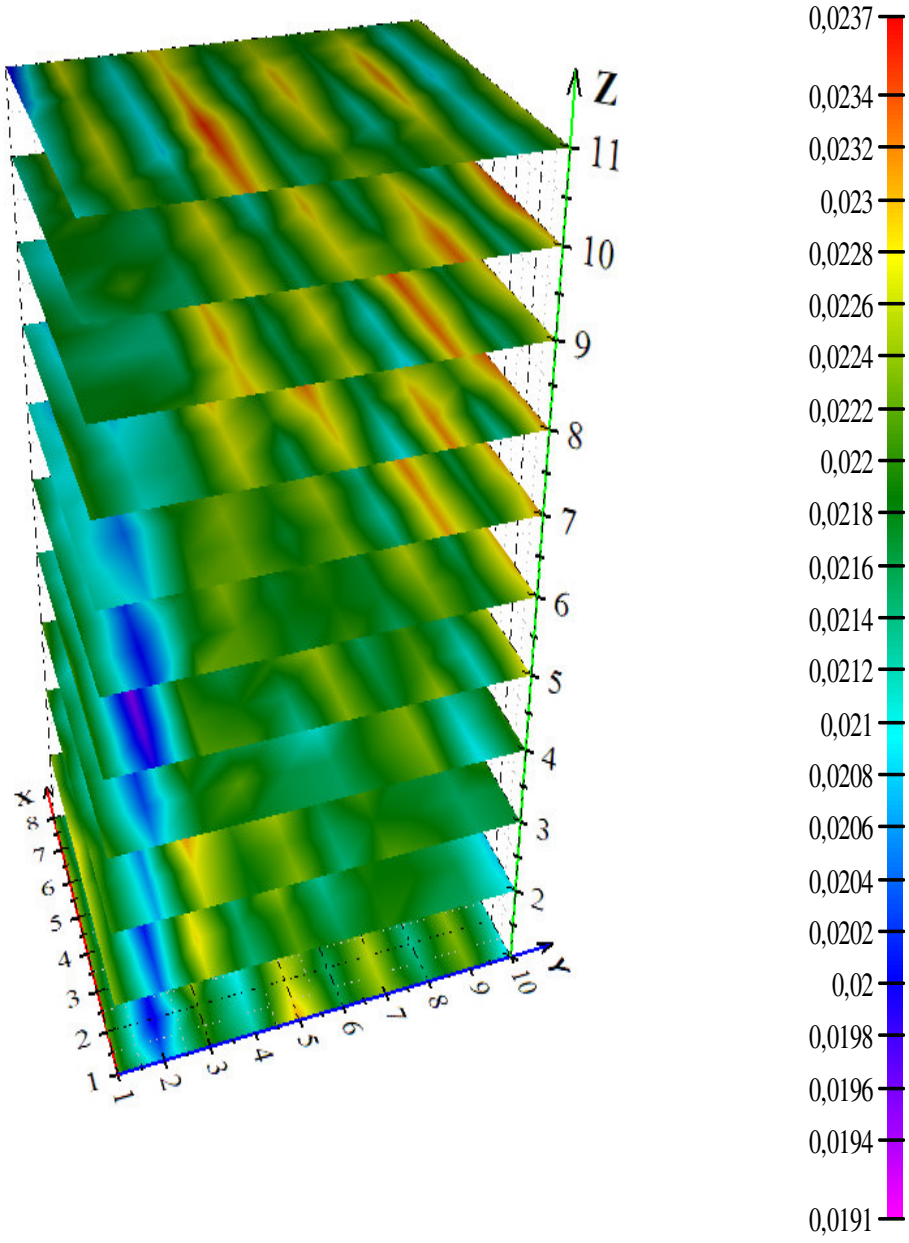


Figure 5.9 shows the full 11 layers of the water bath at 60ºC

Water baths;

In figures 5.2 to 5.9, the 3-D temperature profile of a water bath at different temperatures is shown. In water baths, distilled water was used during the process. Although the 3-D scanner system fits quite well on the water bath, there are still two problems. The first problem is the design of the water bath, and the other one is the temperature differences between the water bath and the laboratory. As the temperature rises from 30ºC to 60ºC, the temperature difference between the laboratory and the water bath increases. The laboratory's temperature was between 20º to 22ºC while all tests were done. Because of the heat transfer between the water bath and the laboratory, the first layers temperatures difference between the two probes are less uniform than the middle or bottom layers of the bath. This can easily be seen by looking at the first layers and the middle layers of the figures 5.2, 5.4, 5.6, 5.8. However, there is another problem at the bottom of the water bath. This is a design problem, the cross-section of the liquid baths are shown in figure 5.1. The heater is at the bottom of the bath and there are three propellers, placed for temperature uniformity of liquids, on the left side of the bath. In the figures the left side of the bath is described as the Y-1 side. Thus, the minimum temperature change in the probes depends on the immersion of the probes and the working temperature because of the heat transfer between the bath and the laboratory. In figures, 5.2, 5.4, 5.6, 5.8 there are four levels shown for each measured temperature. In each figure, comparing the seventh levels will give approximate information about how the two problems affect the results. According to the figures, the average change in the temperature for the seventh layers are 0.0005ºC, 0.0007ºC, 0.0016ºC, and 0.0020ºC. Although all the results are in the range of the manufacturer's guide, from the figures, the position of the propellers can be described from the color changes in the figures. Axis (Y_6 , $X_{1\text{-}4}$). As a result, for the water bath in any temperature range the coordinates, X_4, Y_4, Z_7 gave the maximum uniformity, but not the minimum temperature difference between the probes.

5.2 Oil Bath Results

To scan oil bath the x,y,z values are X=10, Y=2 and Z=85. Intervals between X and Y is 0.6 cm. Z axis interval is 0.15 cm. X,Y and Z axes are 3-D dimensions and the color is the fourth dimension, depending on the temperature and its unit is Celsius.

Oil Bath at 120ºC

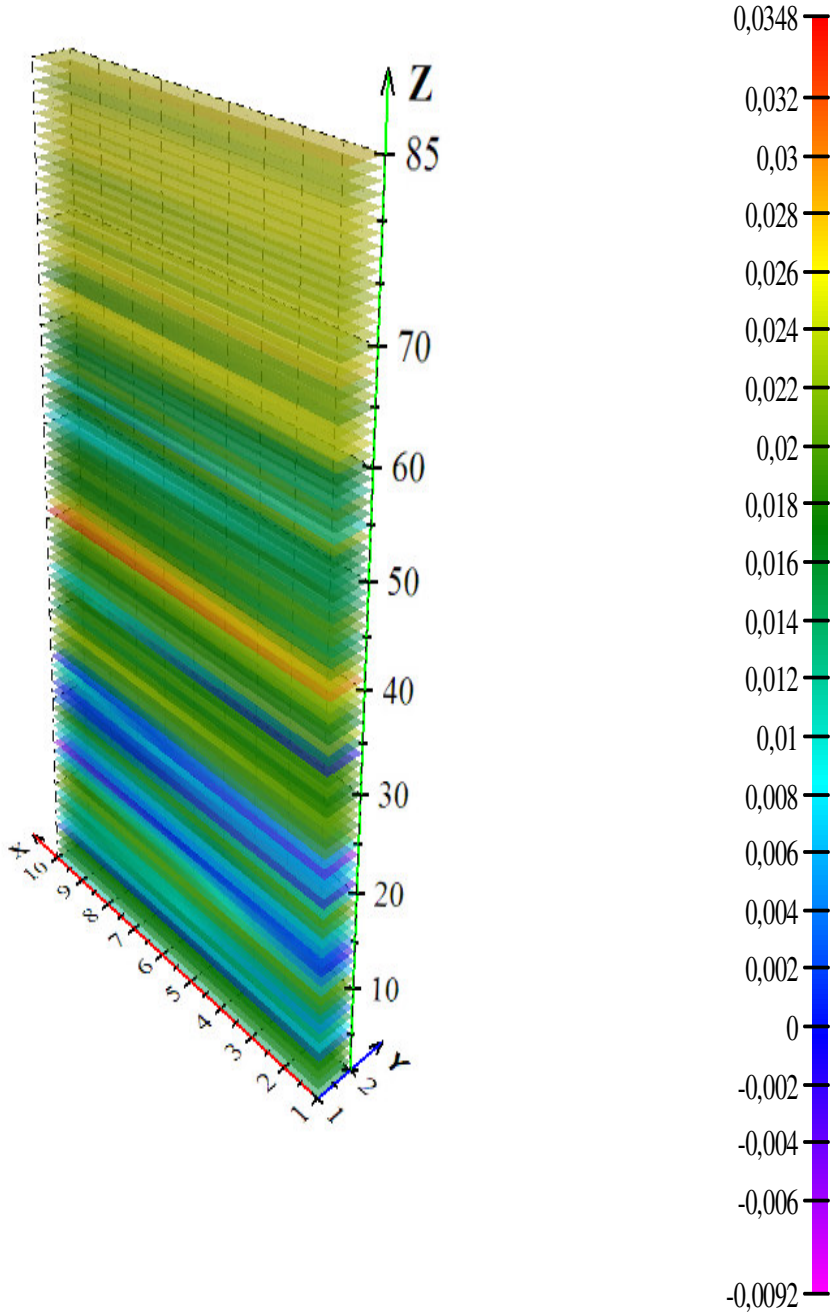


Figure 5.10 shows full 85 layers of the oil bath at 120ºC

Oil Bath at 150ºC

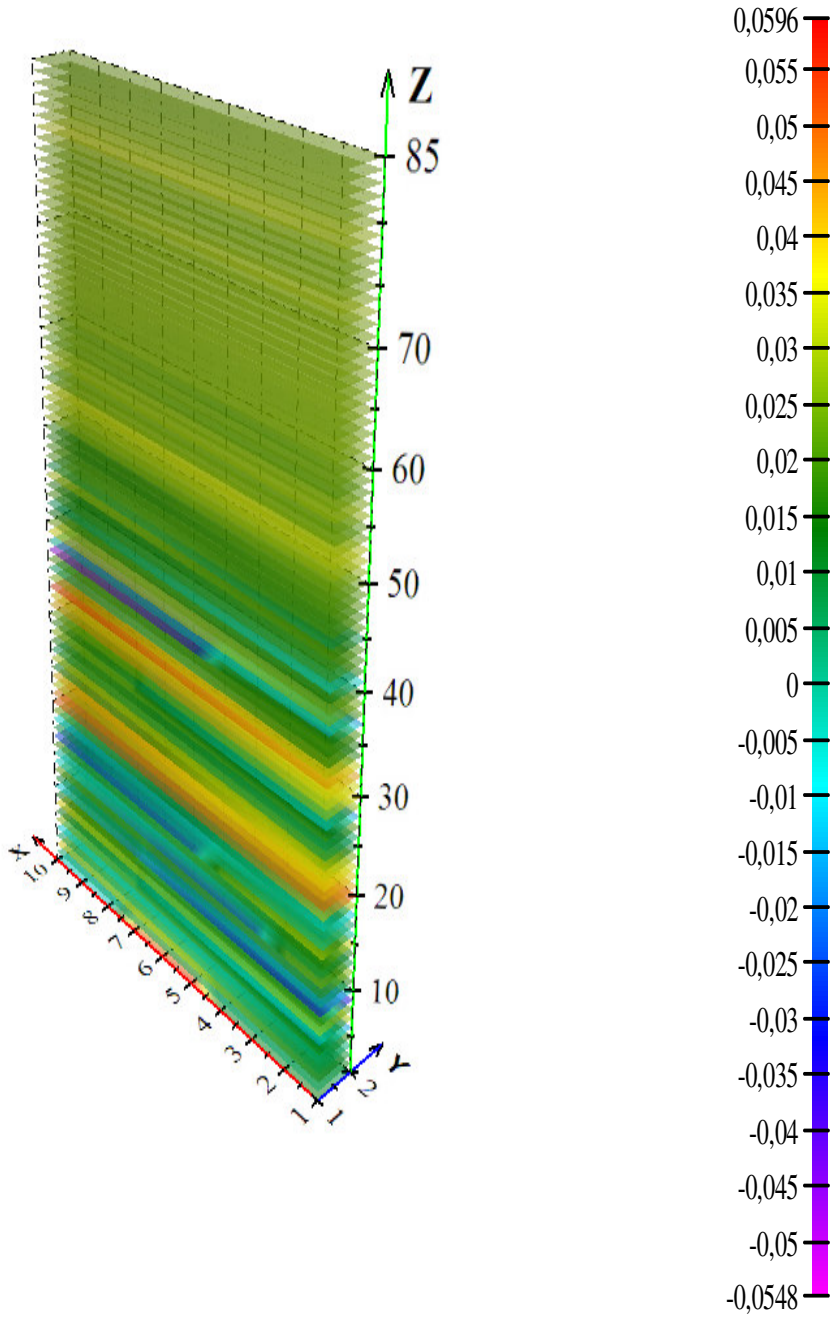


Figure 5.11 shows full 85 layers of the oil bath at 150ºC

Oil Bath at 200ºC

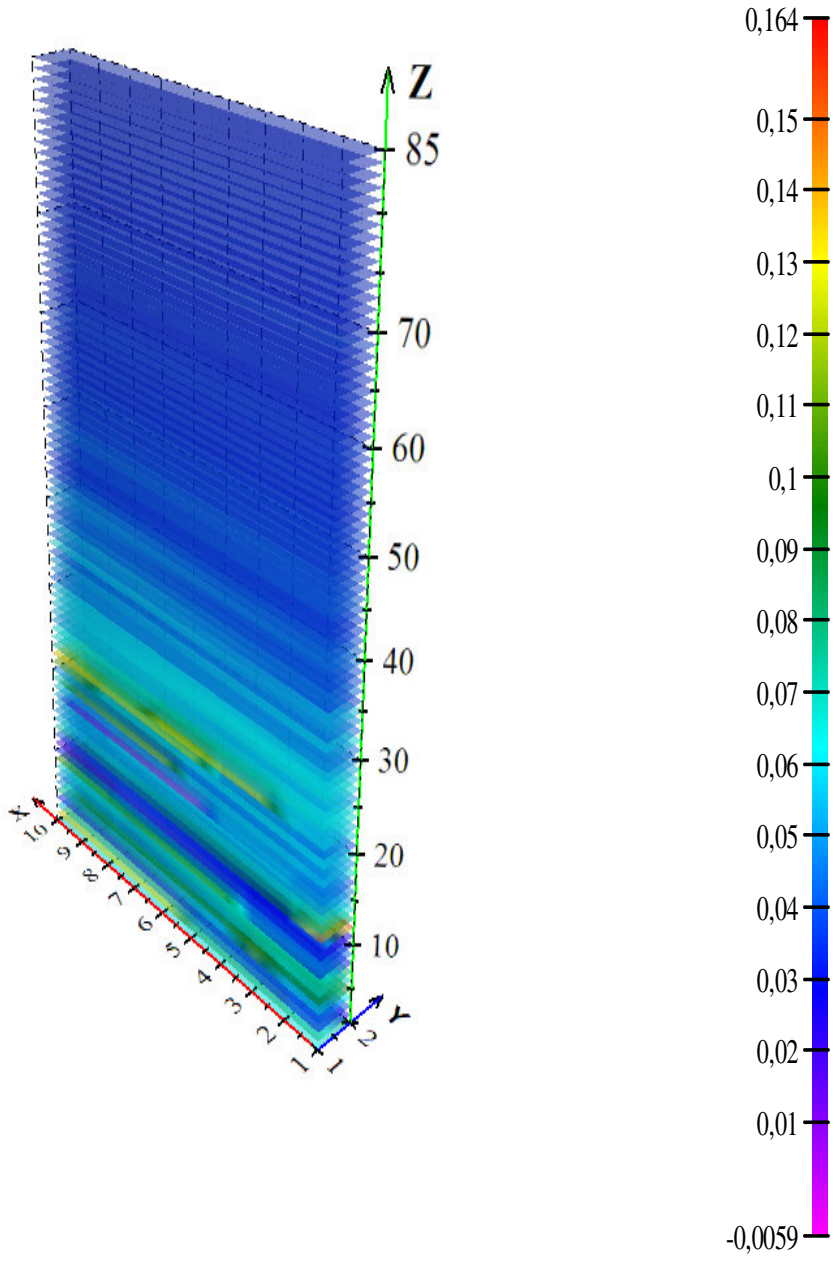


Figure 5.12 shows full 85 layers of the oil bath at 200ºC

Oil Bath at 220ºC

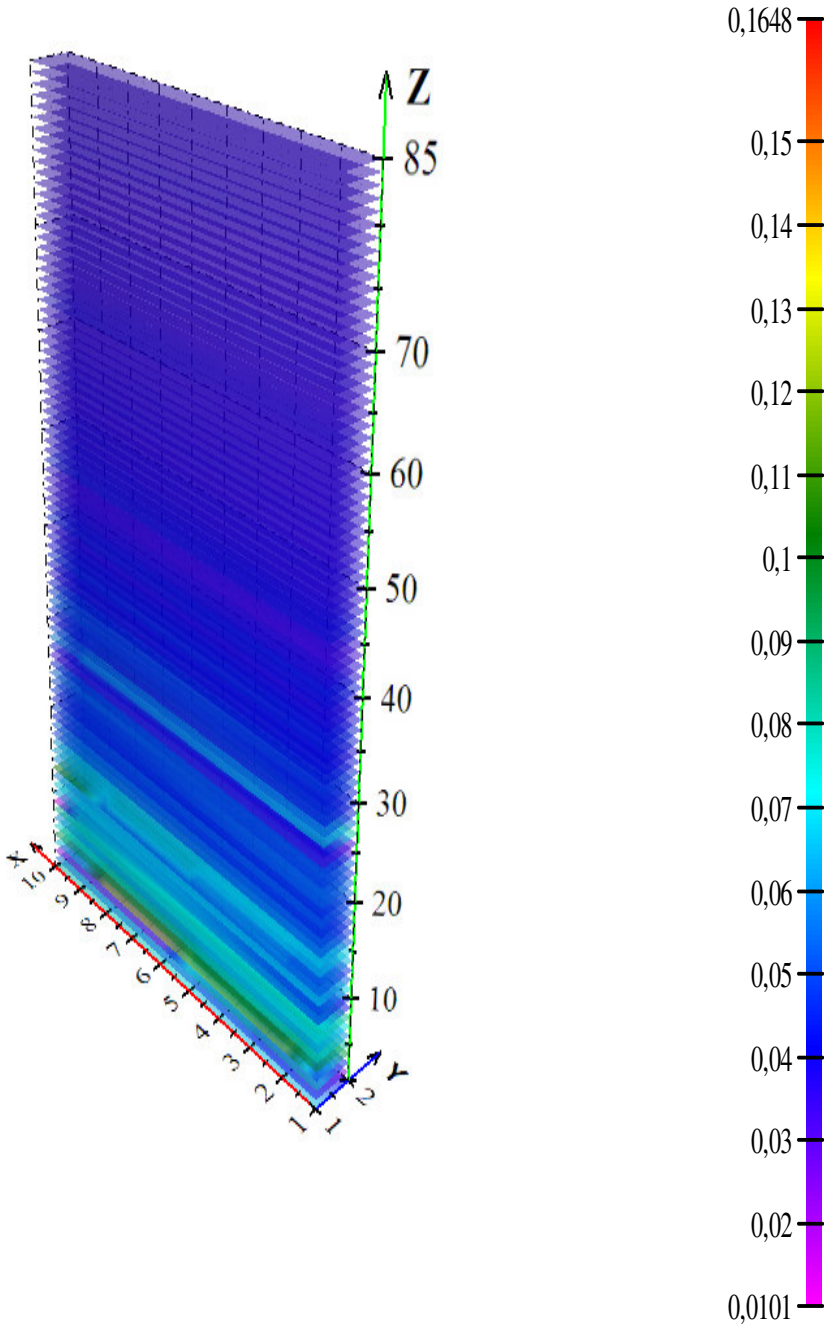


Figure 5.13 shows full 85 layers of the oil bath at 220ºC

Oil baths

The temperature profile study for the oil bath was carried out in a similar way as the water bath. However, the volume that must be scanned is much smaller than the water bath's volume. Thus, to obtain better results, the intervals of the steps decreased to 1.5 mm . Due to the design of the oil bath, the 3-D scanner system is placed on the top of a small circular area of the oil bath. Although higher temperatures are used, the heat transfer between the laboratory temperature and the oil bath temperature is assumed to be lower to the water bath, due to the small circular area on the top of the bath. In this study, the temperature profile of oil bath is depicted by 85 layers. In Figures 5.10 to 5.13, the whole 85 layers can be seen. The data obtained from the oil bath again consist of temperature differences between the two probes. Although, the temperature rose from 120ºC to 220ºC, the temperature differences were found to be between 0.026ºC - 0.030ºC and the oil bath became more uniform at higher temperatures. As the temperature of the oil bath increased, the temperature difference between the layers become uniform compared to low temperatures of the bath. As seen from the figures 5.10 to 5.13 at lower temperatures, the uniformity starts from the 60^{th} layer but in 220 ° C, the uniformity starts from the 30^{th} layer. Thus, the probes must be immersed at least nine cm from the surface of the oil to obtain better results.

5.3 Salt Bath Results

According to the structure of the salt bath, the 3-D scanner device worked in only one dimension called Z. Due to this, the structures of the graphs are two dimensional line graphs. The graphs are plotted at 300ºC, 350ºC, 400ºC and 450ºC temperatures of the salt bath. At each temperature value there are two types of graphs. In the first type of graph there are two probes, one is fully immersed and fixed at the bottom of the bath and the other one is moved from the bottom of the bath in an inverval of 1mm. The X-axis indicates the data taken during the process, every fourth data point describes a 1mm movement of the active probe, Y-1, and Y-2 axis are the data read outs from the probes. In the graphs, the values are absolute values they are not the temperature differences of the probes.

Salt bath at 300ºC one probe is fixed other is moving

For figures, 5.14-5.29 there are two Y-axes and one X-axis the different colors indicates different probes. The Y-axis depends on the temperature and the X- axis depends on the intervals. In figure 5.29, the full graph is shown, from figures 5.14 to 5.28 the full graph is split for better resolution. Blue line is moving probe black line is fixed probe.

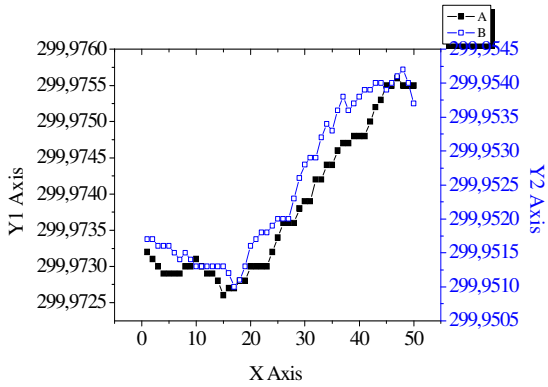


Figure 5.14

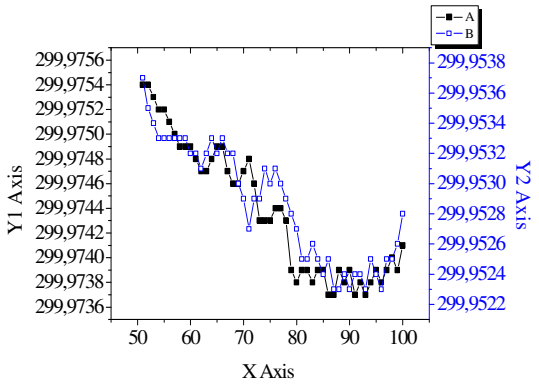


Figure 5.15

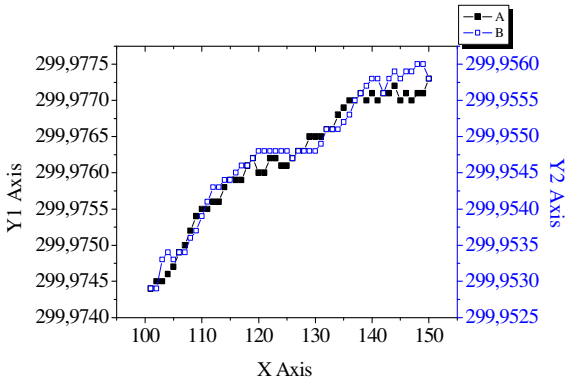


Figure 5.16

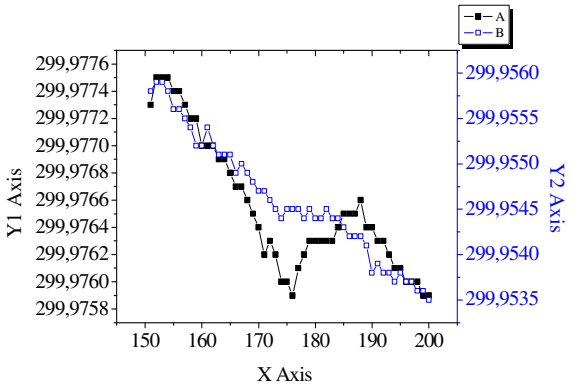


Figure 5.17

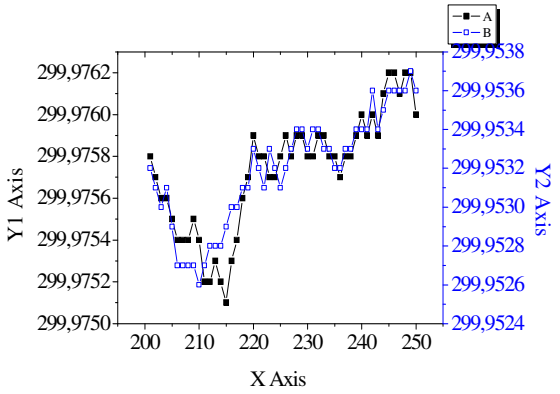


Figure 5.18

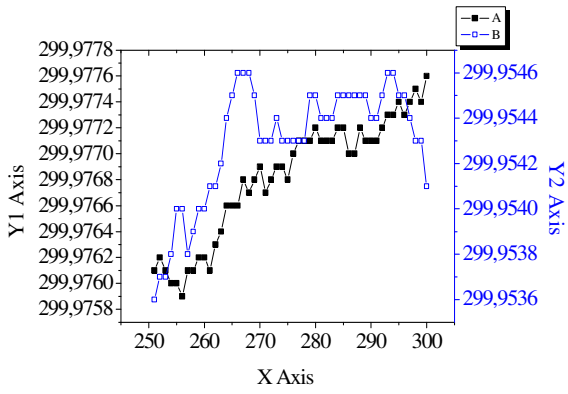


Figure 5.19

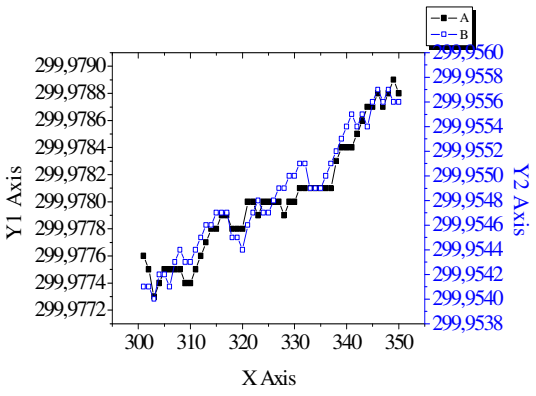


Figure 5.20

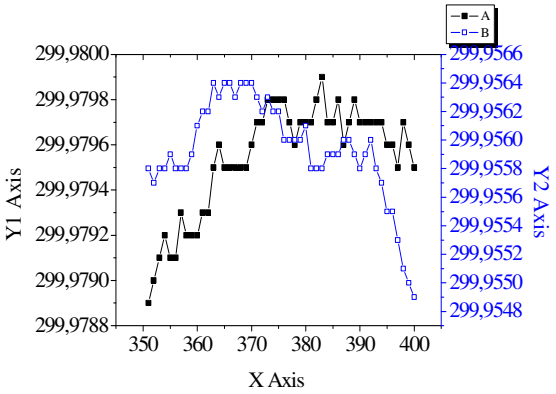


Figure 5.21

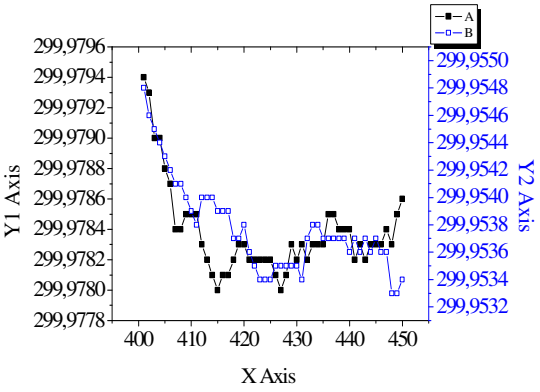


Figure 5.22

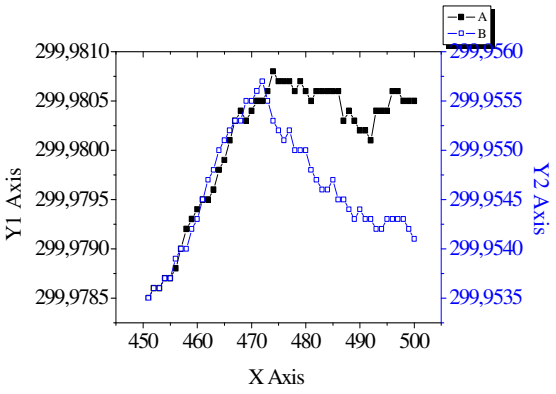


Figure 5.23

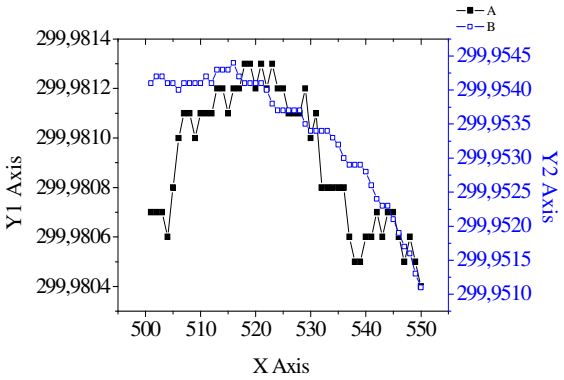


Figure 5.24

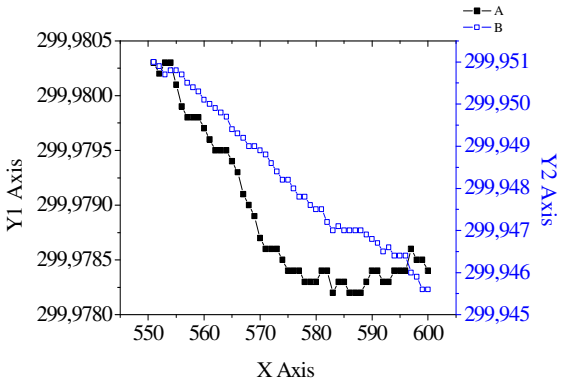


Figure 5.25

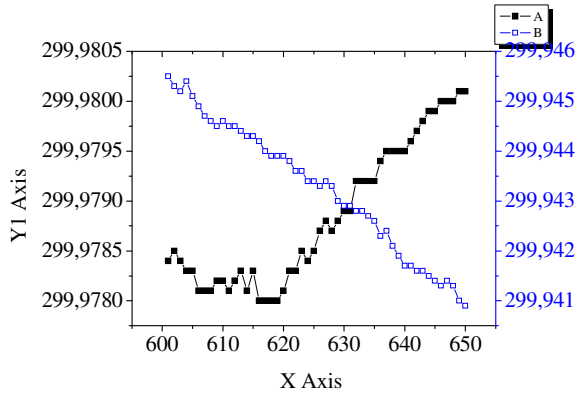


Figure 5.26

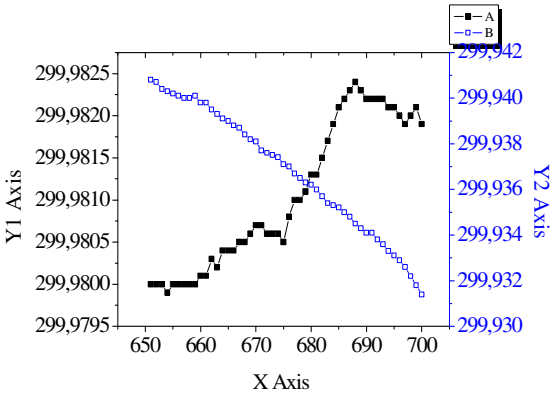


Figure 5.27

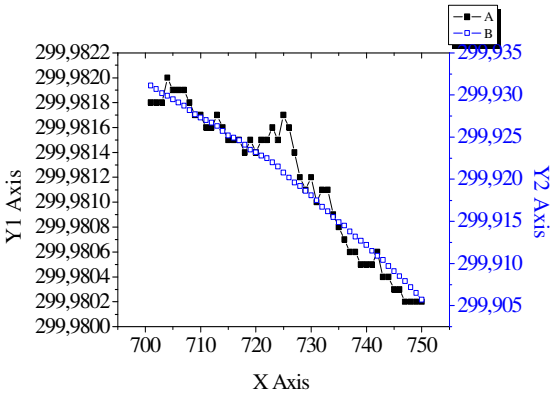


Figure 5.28

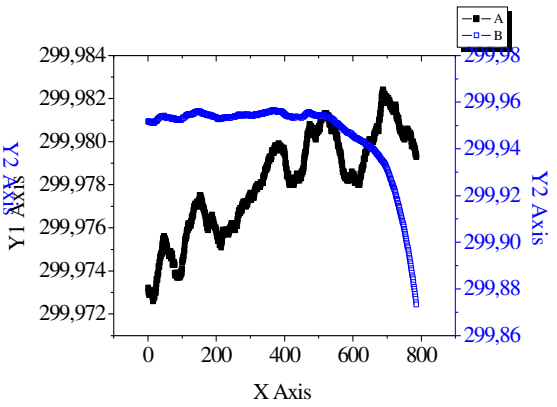


Figure 5.29

Blue line is moving probe black line is fixed probe

Salth Bath at 300ºC All the probes are moving

For figures, 5.30-5.45 there are two Y-axes and one X-axis the different colors indicates different probes. The Y-axis depends on the temperature and the X- axis depends on the intervals. In figure 5.45 the full graph is shown, from figures 5.30 to 5.44 the full graph is split for better resolution. In this study the two probes are moving from the bottom of the salt bath to the surface.

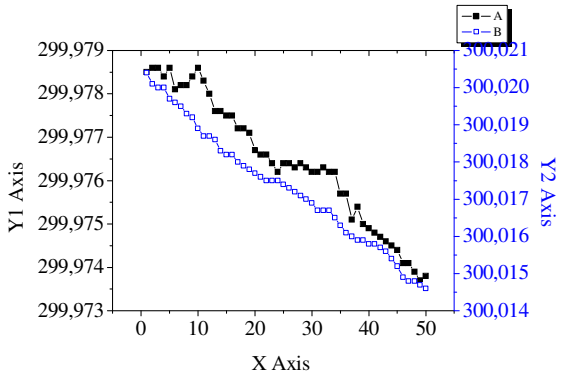


Figure 5.30

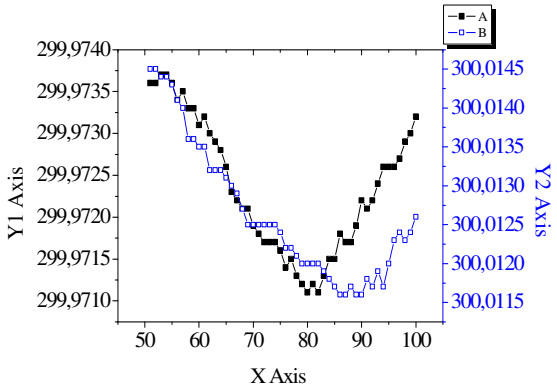


Figure 5.31

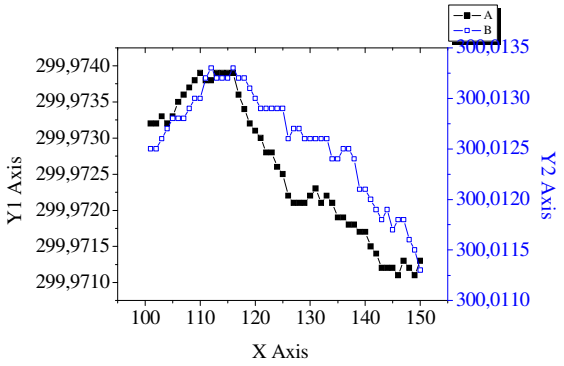


Figure 5.32

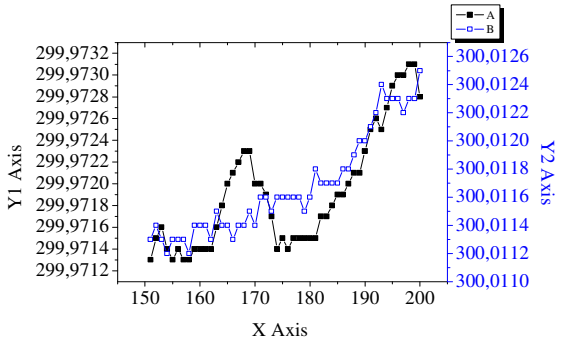


Figure 5.33

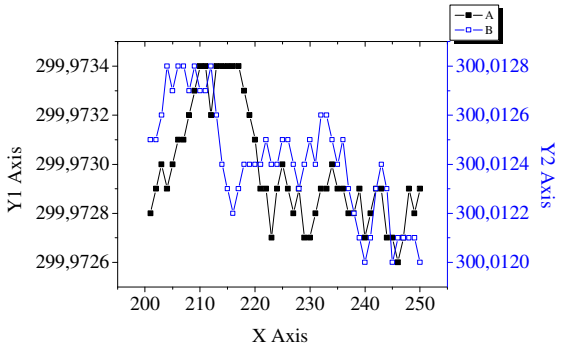


Figure 5.34

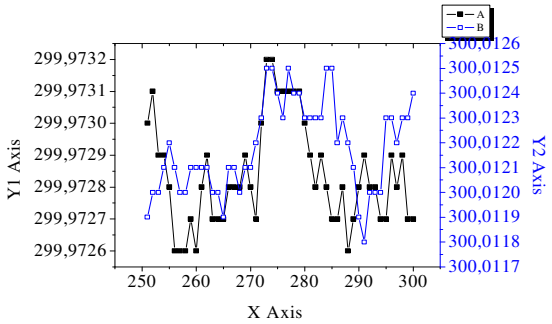


Figure 5.35

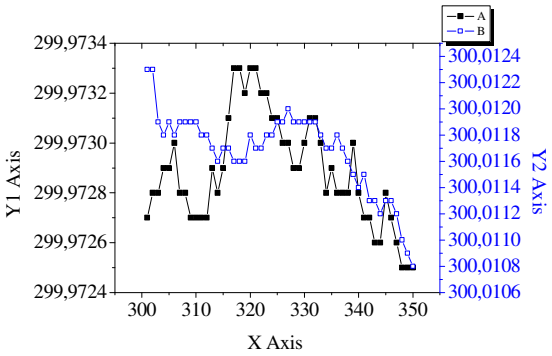


Figure 5.36

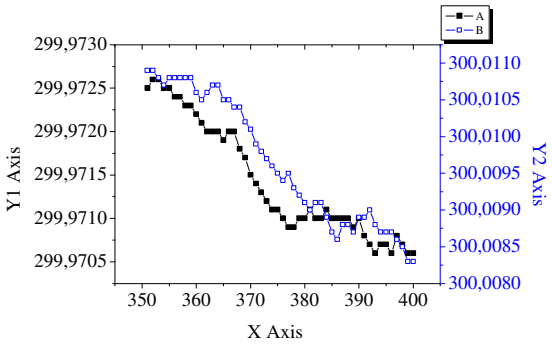


Figure 5.37

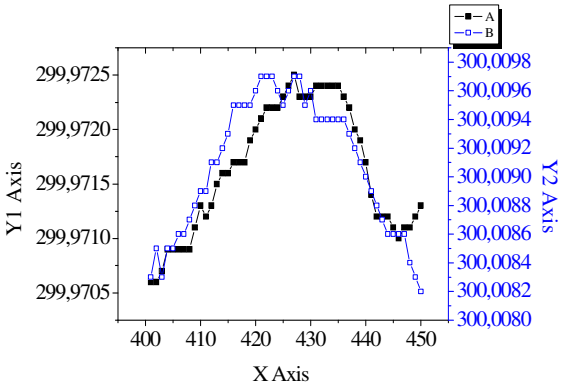


Figure 5.38

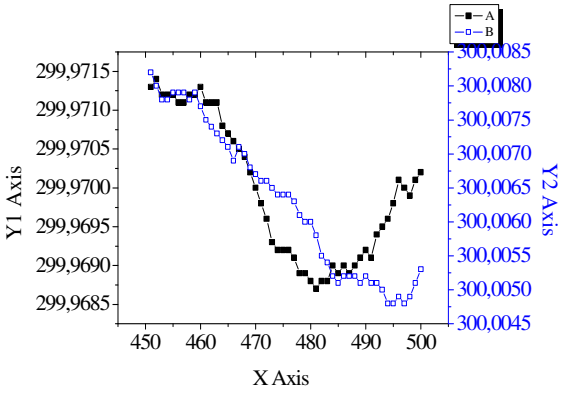


Figure 5.39

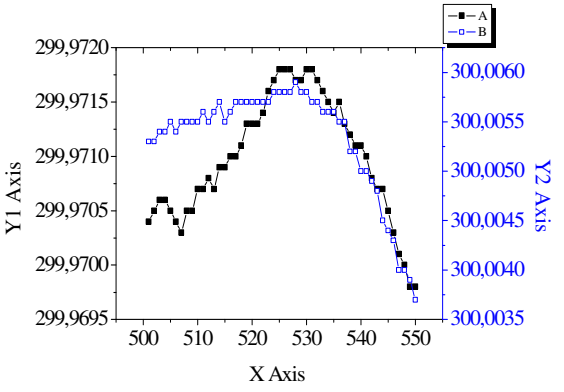


Figure 5.40

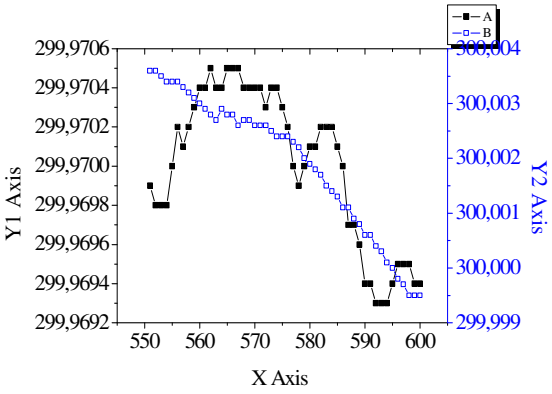


Figure 5.41

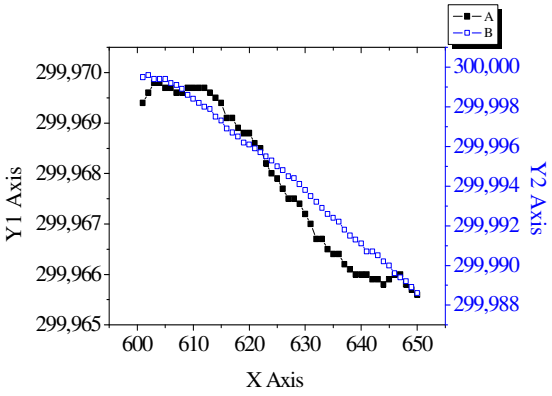
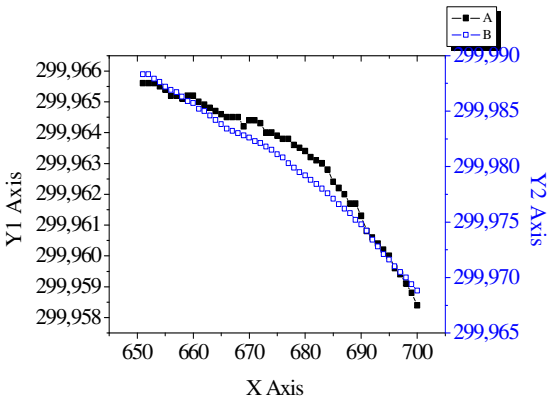


Figure 5.42



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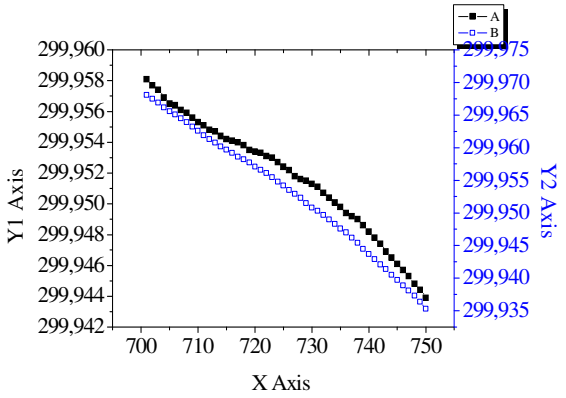


Figure 5.44

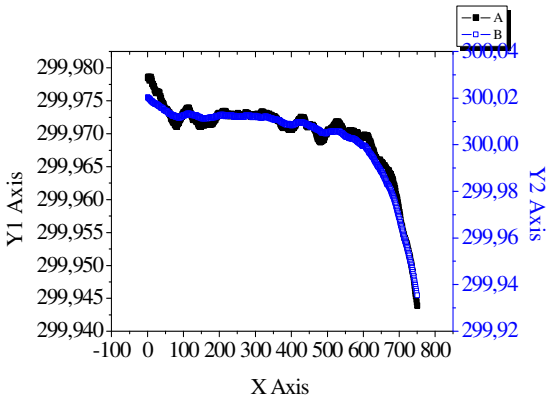


Figure 5.45

Salt Bath at 350ºC one probe is fixed, other probe is moving

For figures, 5.46-5.57 there are two Y-axes and one X-axis the different colors indicates different probes. The Y-axis depends on the temperature and the X- axis depends on the intervals. In figure 5.57, the full graph is shown, from figures 5.46 to 5.56 the full graph is split for better resolution. In this study, there are less graphs since the temperature change reached a higher temperature value before the expected coordinate. Blue line is fixed probe black line is moving probe.

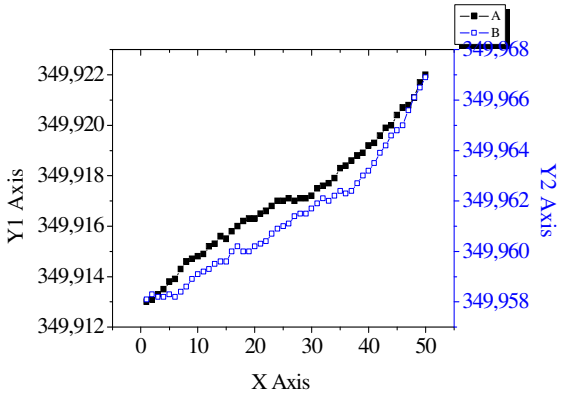


Figure 5.46

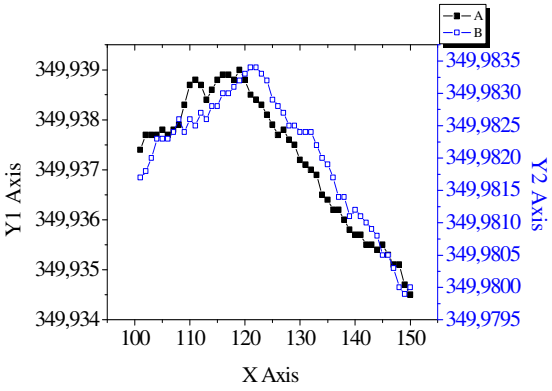


Figure 5.48

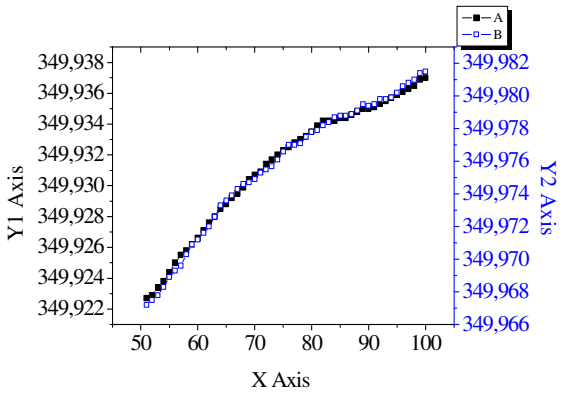


Figure 5.47

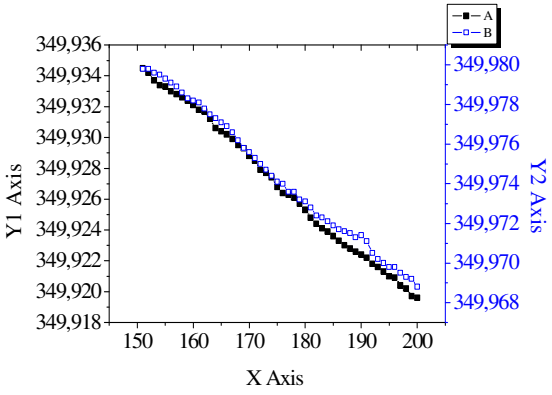


Figure 5.49

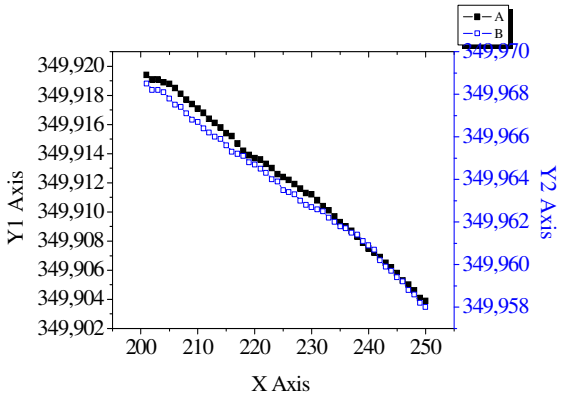


Figure 5.50

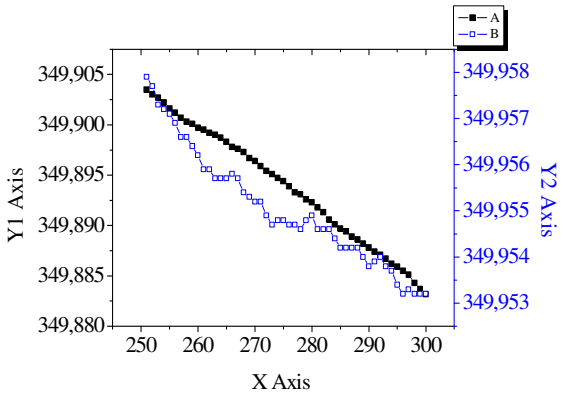


Figure 5.51

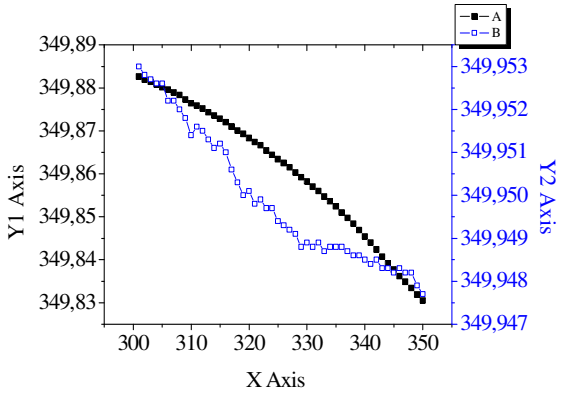


Figure 5.52

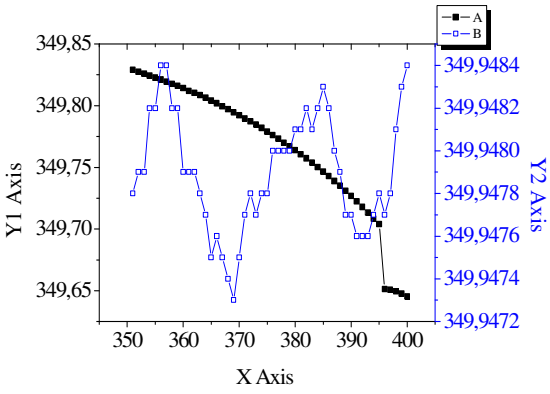


Figure 5.53

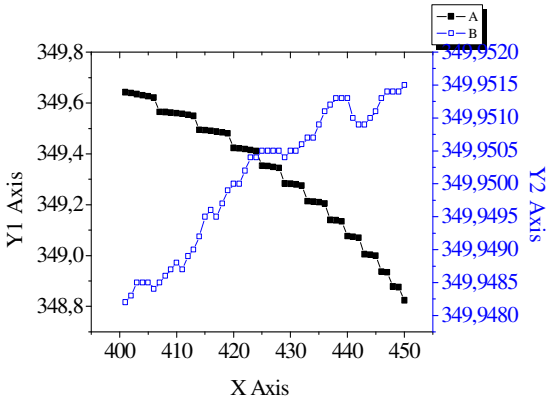


Figure 5.54

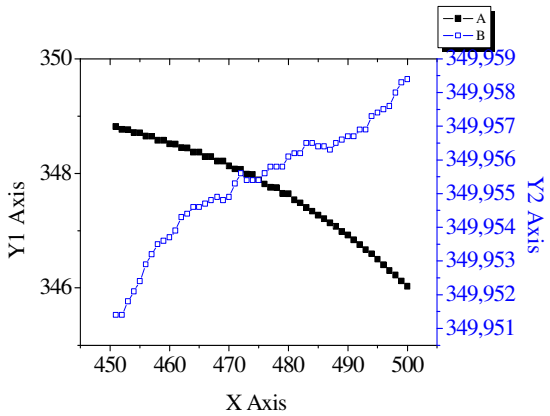


Figure 5.55

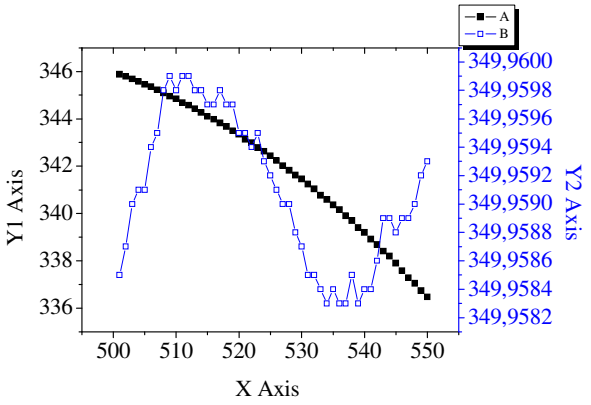


Figure 5.56

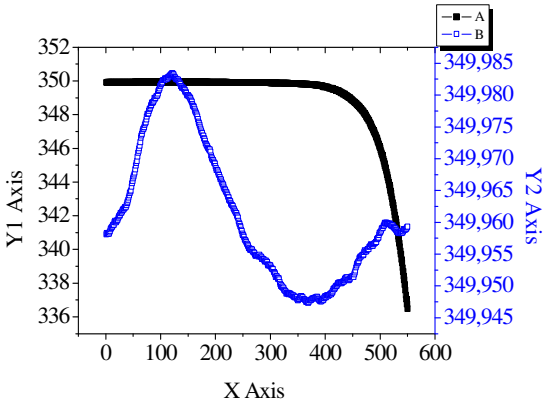


Figure 5.57

Blue line is fixed probe black line is moving probe

Salt Bath at 350ºC All the probes are moving

For figures, 5.58-5.73 there are two Y-axes and one X-axis the different colors indicates different probes. The Y-axis depends on the temperature and the X- axis depends on the intervals. In figure 5.73 the full graph is shown, from figures 5.58 to 5.72 the full graph is split for better resolution

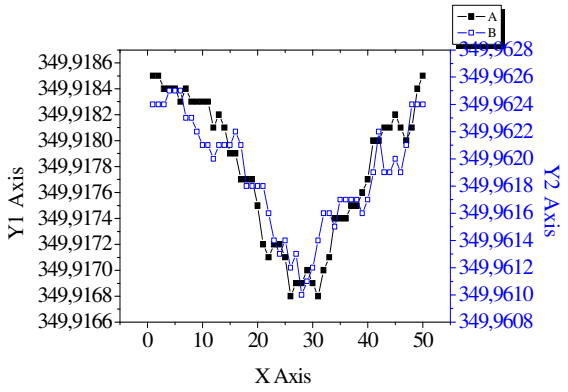


Figure 5.58

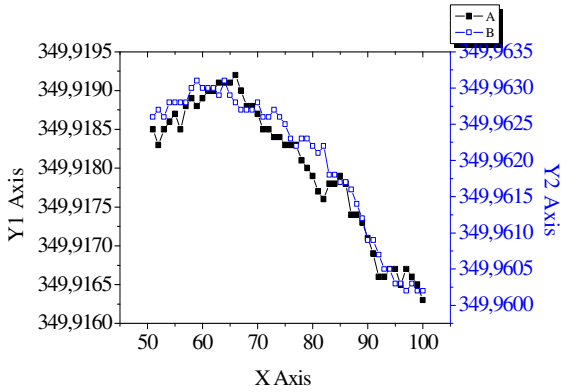


Figure 5.59

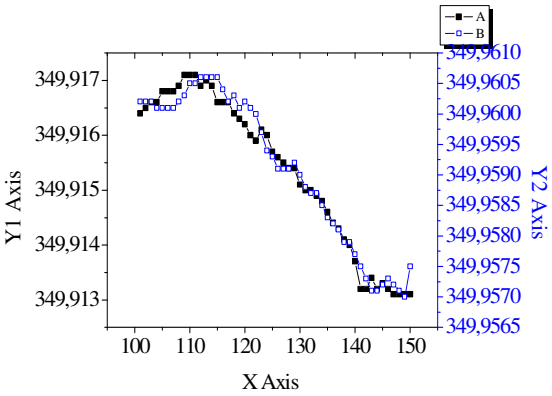


Figure 5.60

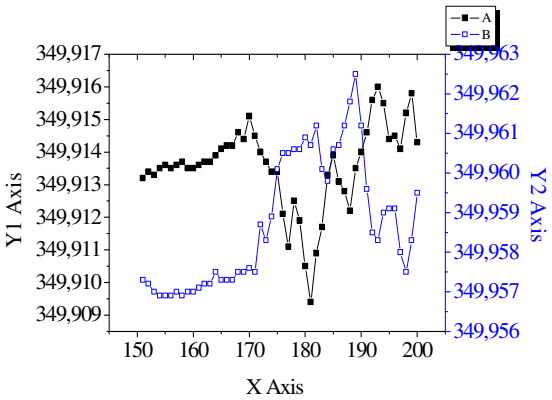


Figure 5.61

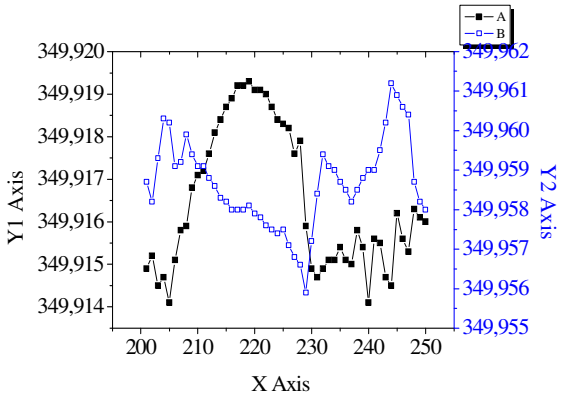


Figure 5.62

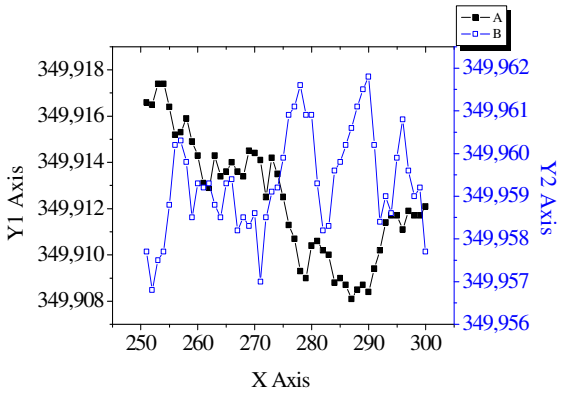


Figure 5.63

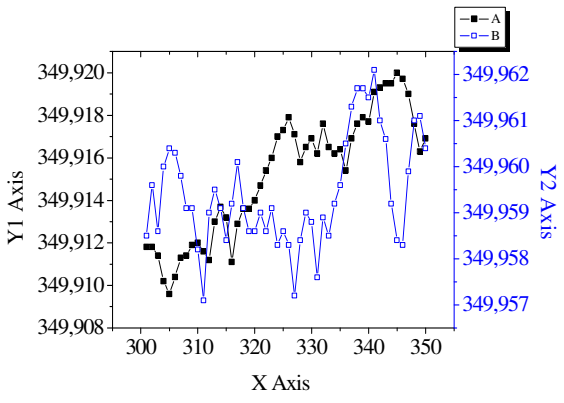


Figure 5.64

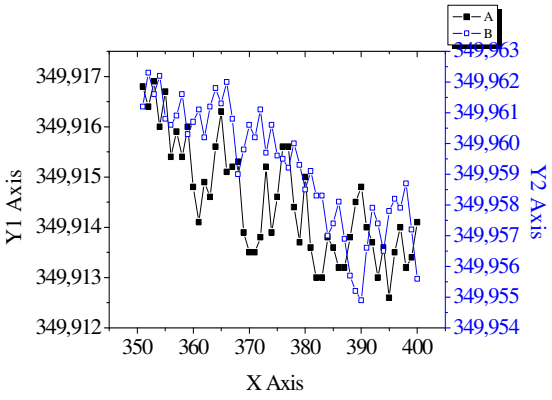


Figure 5.65

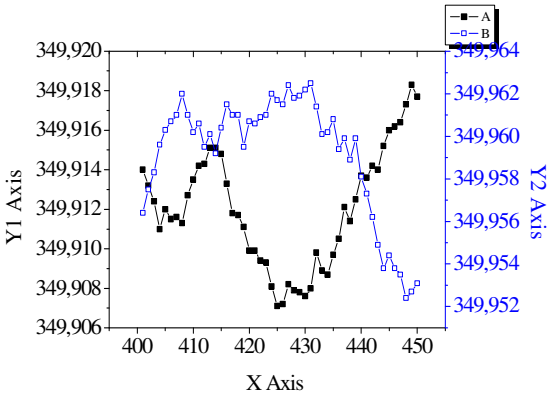


Figure 5.66

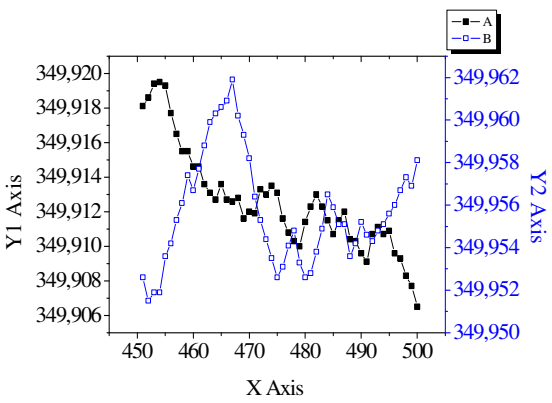


Figure 5.67

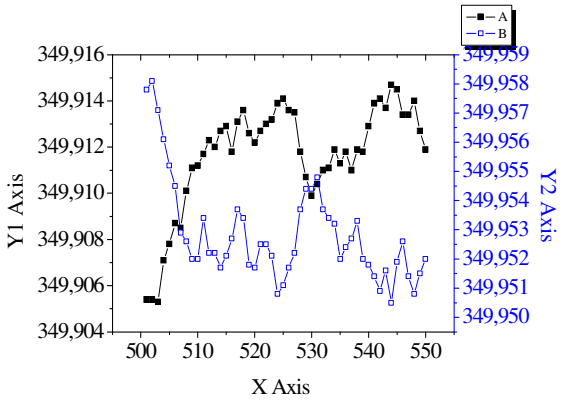


Figure 5.68

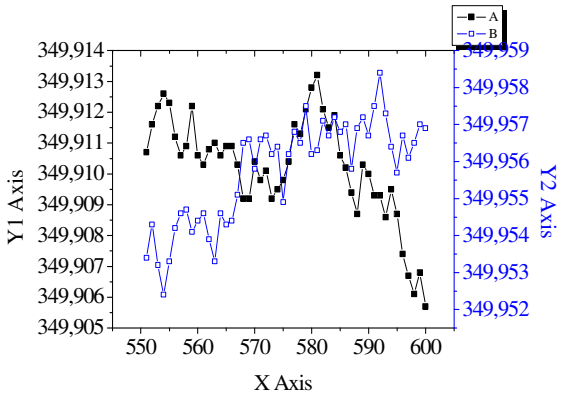


Figure 5.69

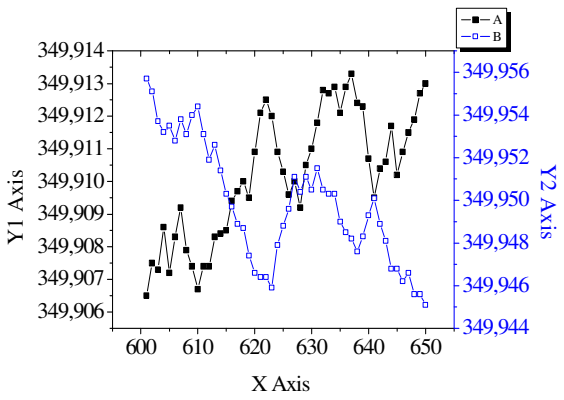


Figure 5.70

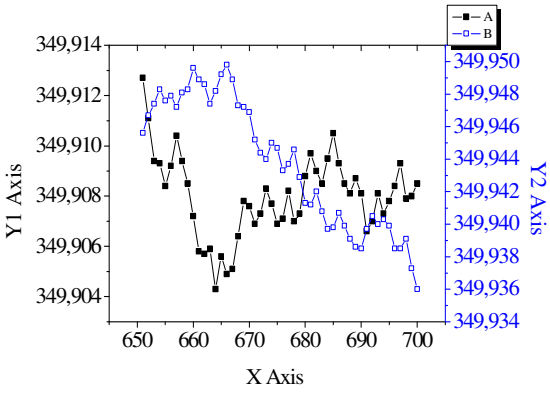


Figure 5.71

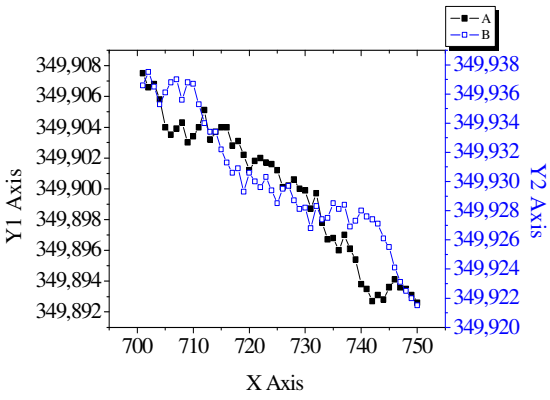


Figure 5.72

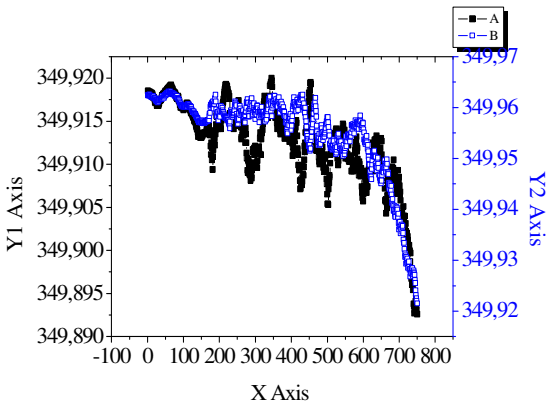


Figure 5.73

Salt Bath at 400ºC one probe is fixed, other one is moving

For figures, 5.74-5.89 there are two Y-axes and one X-axis the different colors indicates different probes. The Y-axis depends on the temperature and the X- axis depends on the intervals. In figure 5.89 the full graph is shown, from figures 5.74 to 5.88 the full graph is split for better resolution. Blue line is fixed probe black line is moving probe.

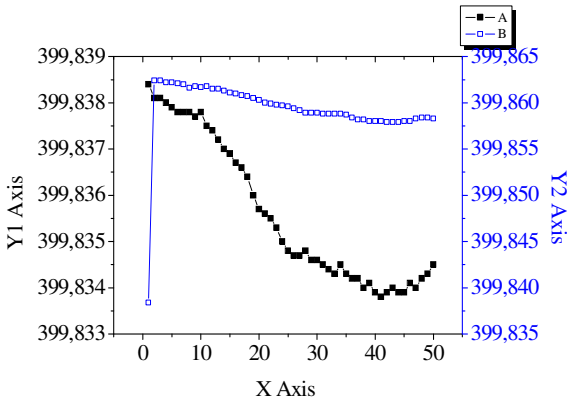


Figure 5.74

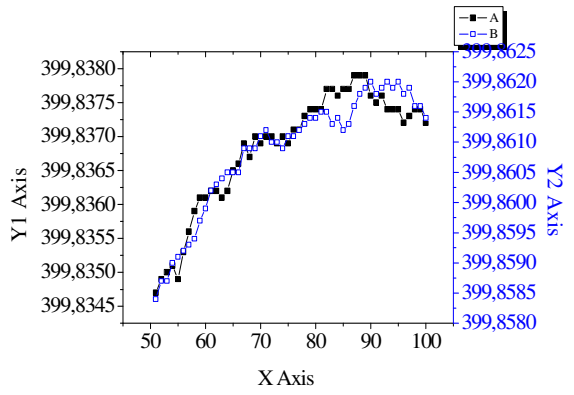


Figure 5.75

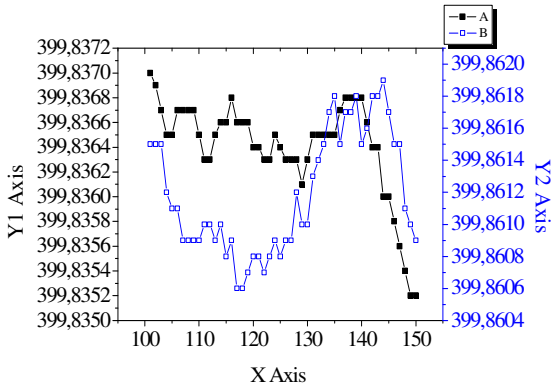


Figure 5.76

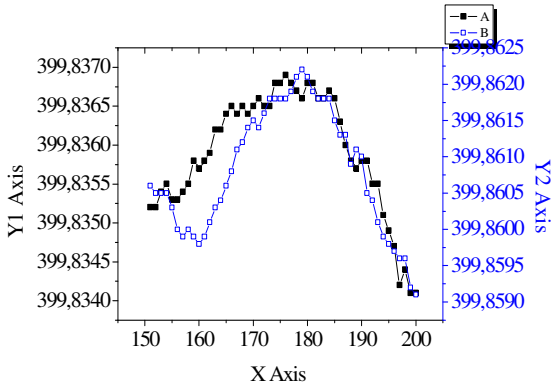


Figure 5.77

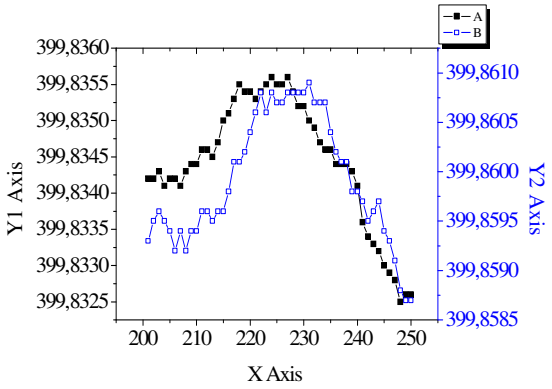


Figure 5.78

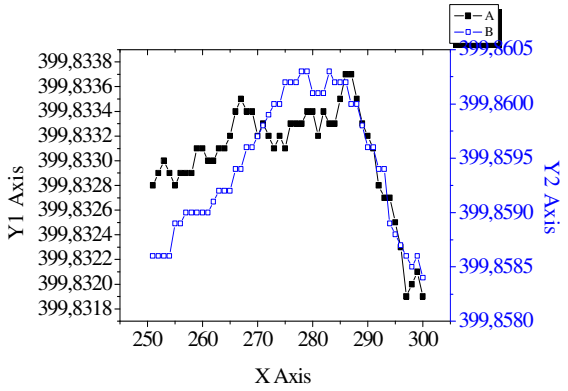


Figure 5.79

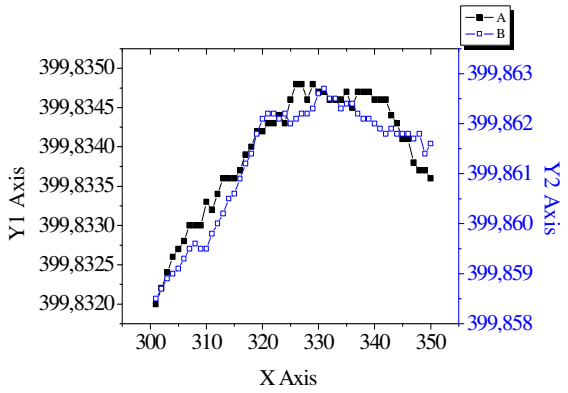


Figure 5.80

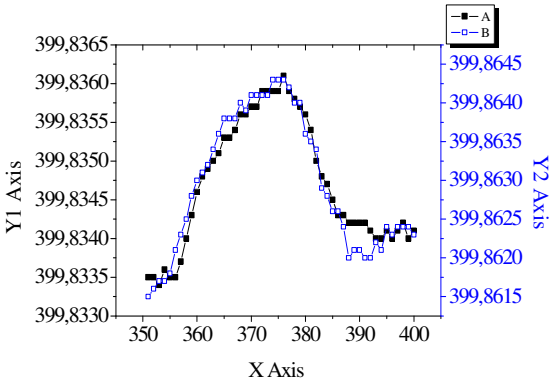


Figure 5.81

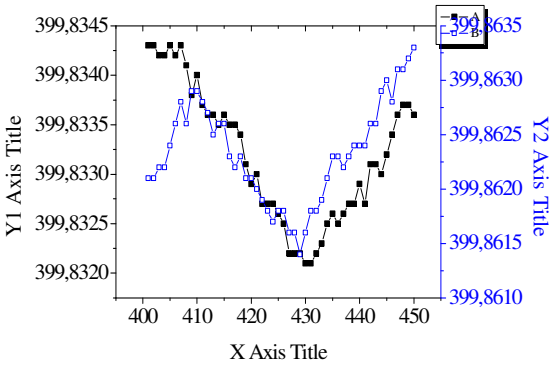


Figure 5.82

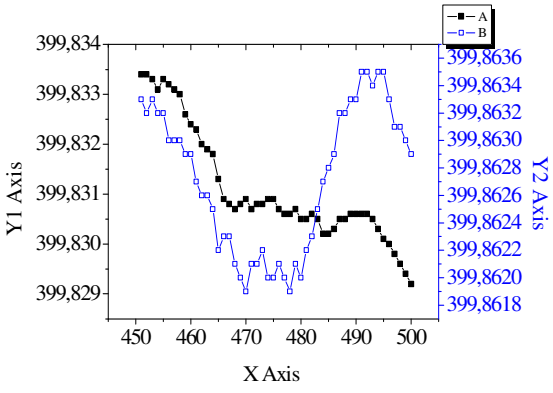


Figure 5.83

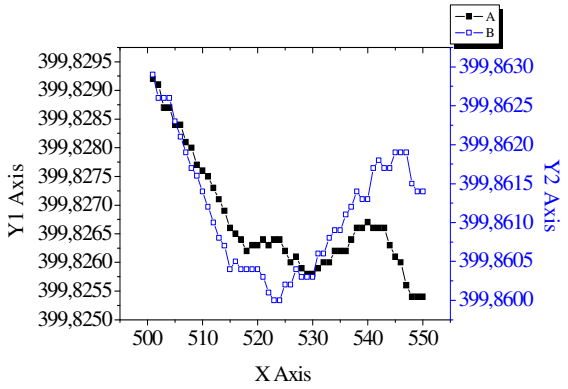


Figure 5.84

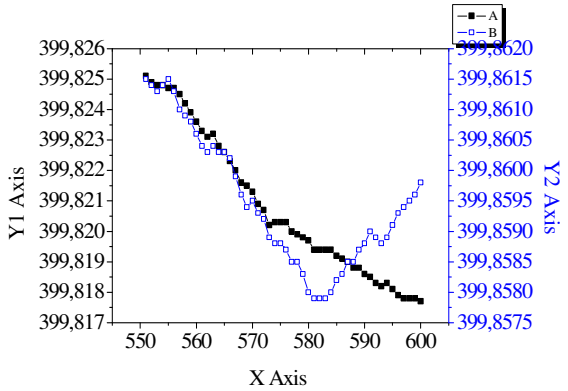


Figure 5.85

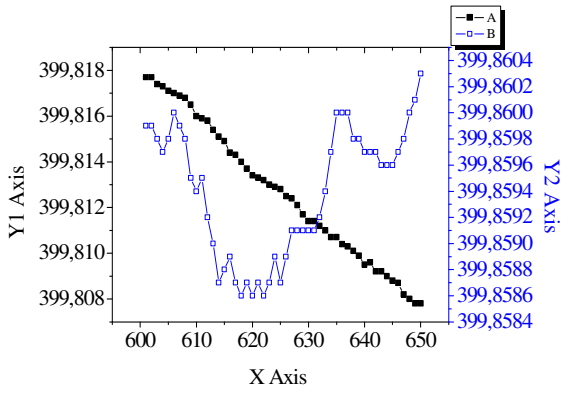


Figure 5.86

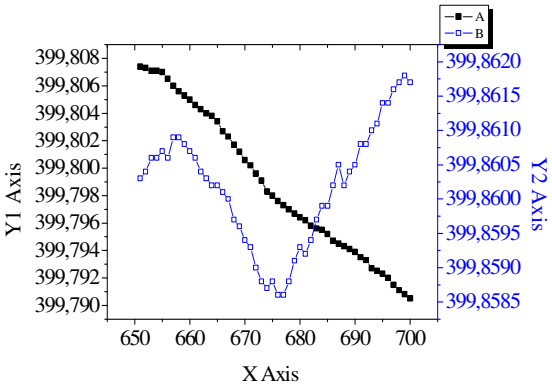


Figure 5.87

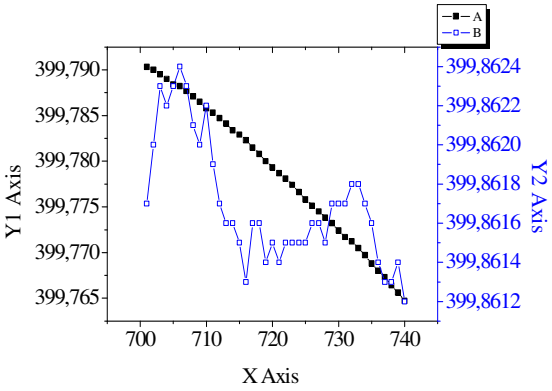


Figure 5.88

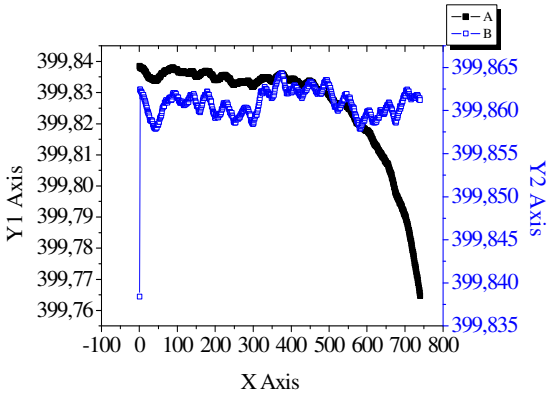
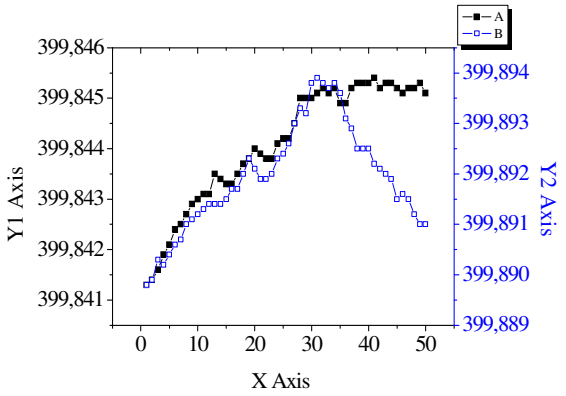


Figure 5.89

blue line is fixed probe black line is moving probe

Salt bath at 400ºC all the probes are moving

For figures, 5.90-5.105 there are two Y-axes and one X-axis the different colors indicates different probes. The Y-axis depends on the temperature and the X- axis depends on the intervals. In figure 5.105 the full graph is shown, from figures 5.90 to 5.104 the full graph is split for better resolution.



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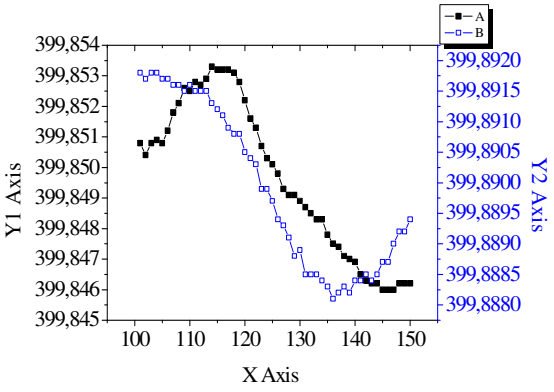

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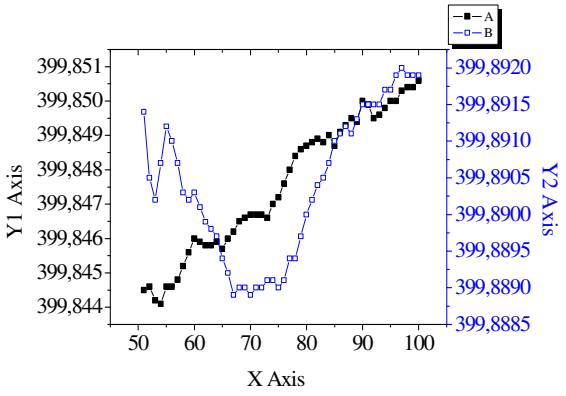

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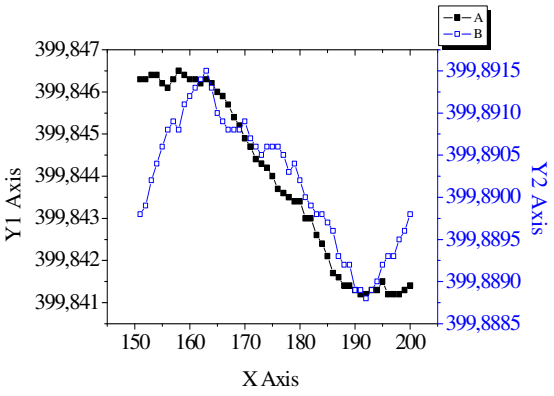

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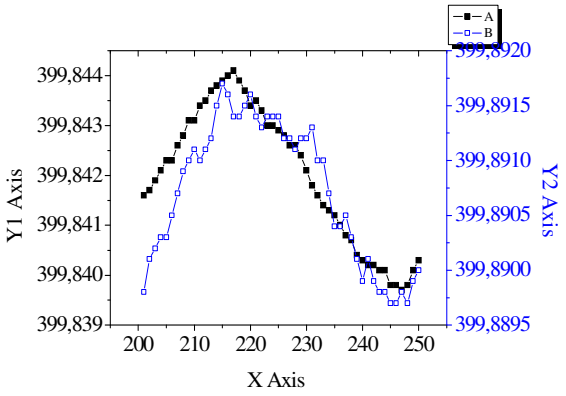

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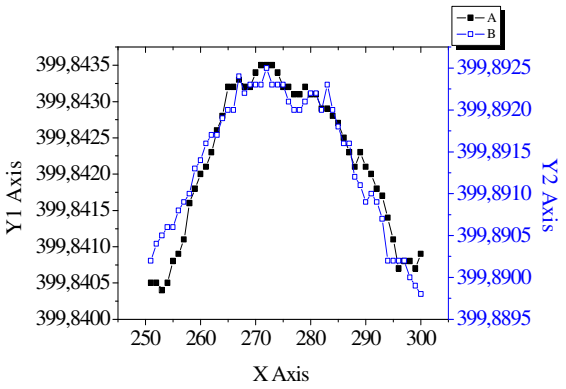

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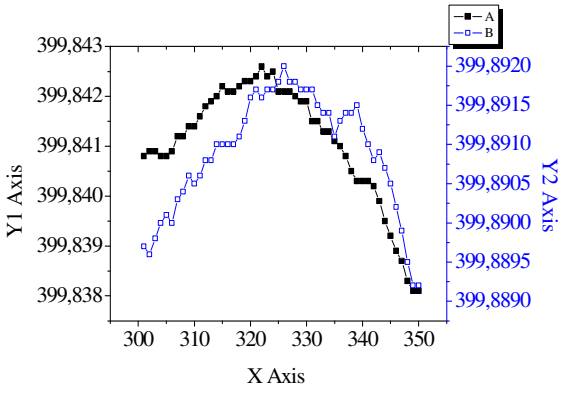

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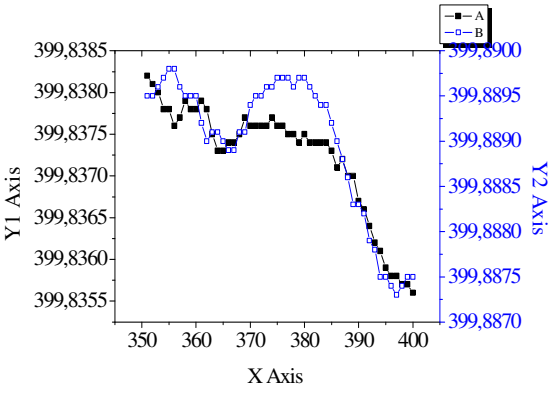

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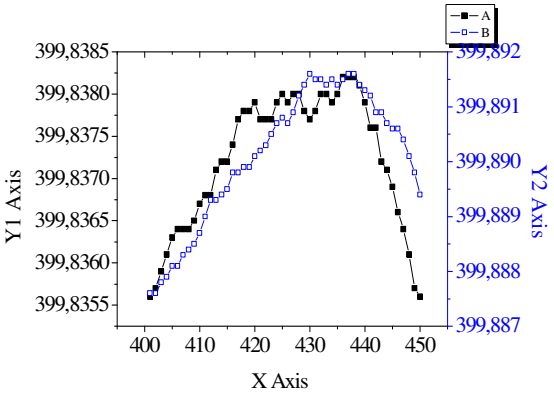

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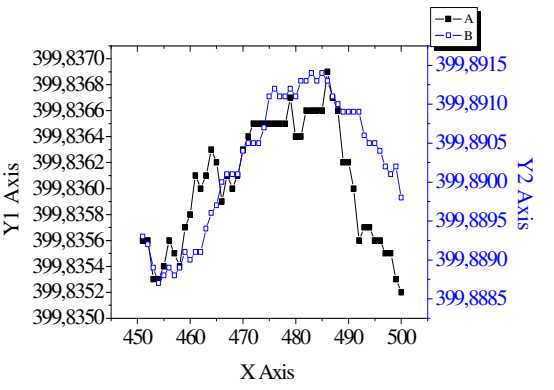

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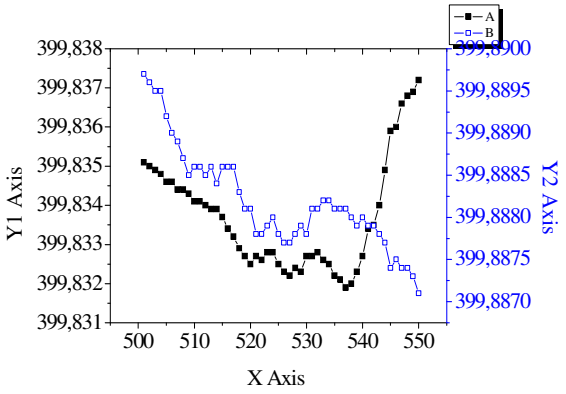

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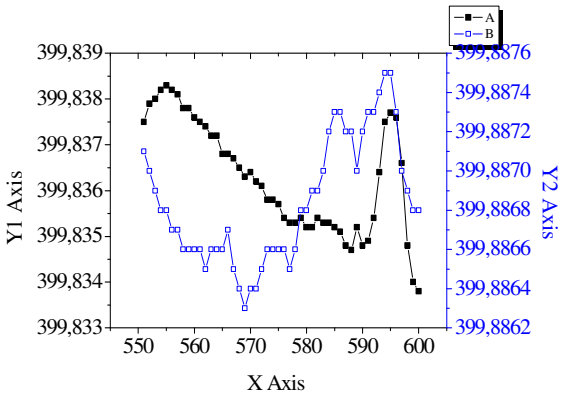

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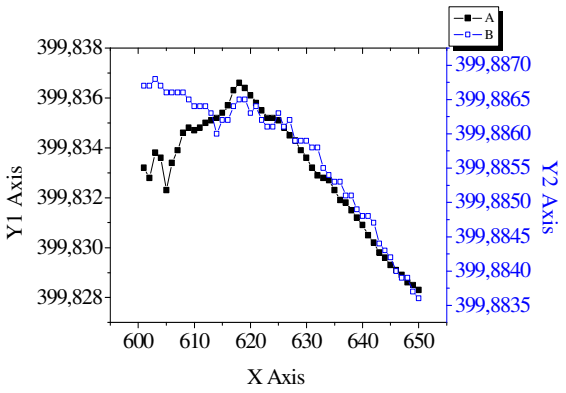

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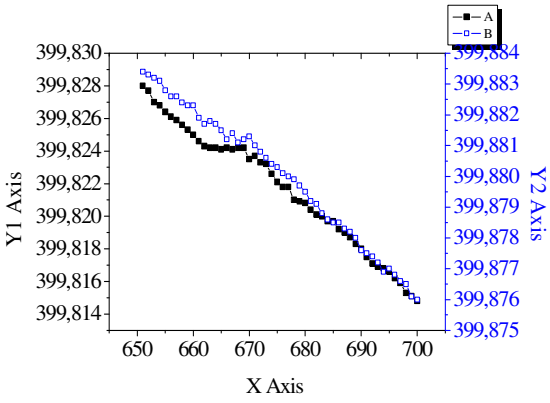

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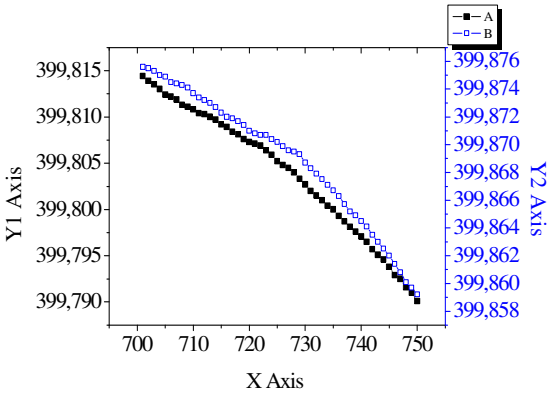


Figure 5.104

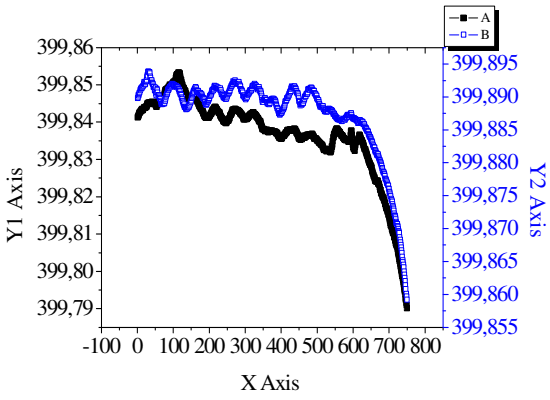


Figure 5.105

Salt Bath at 450ºC one probe is fixed, other one is moving

For figures, 5.106-5.121 there are two Y-axes and one X-axis the different colors indicates different probes. The Y-axis depends on the temperature and the X- axis depends on the intervals. In figure 5.121 the full graph is shown, from figures 5.106 to 5.120 the full graph is split for better resolution. Blue line is fixed probe black line is moving probe.

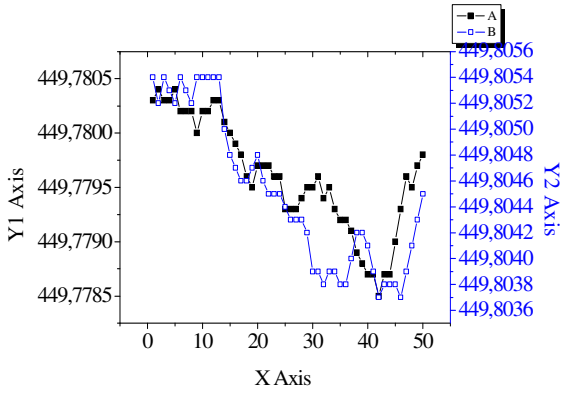


Figure 5.106

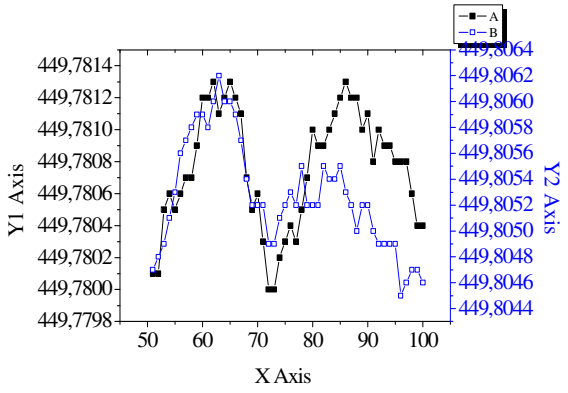
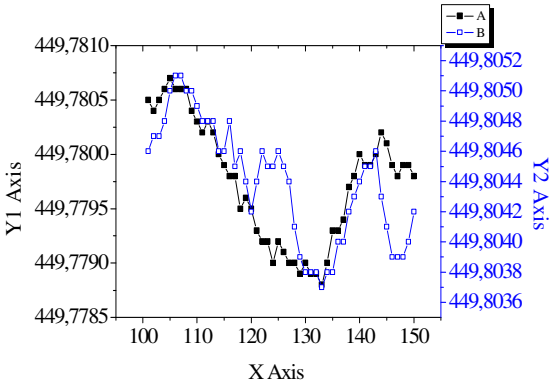


Figure 5.107



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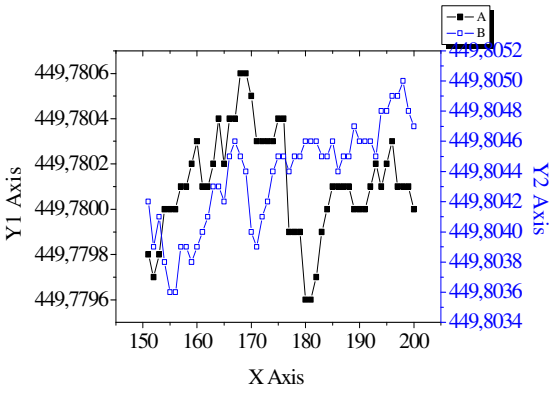

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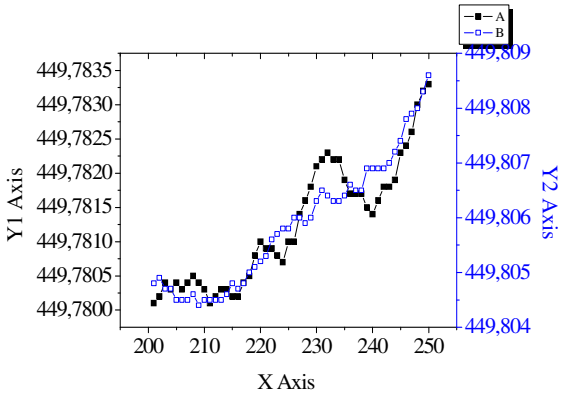

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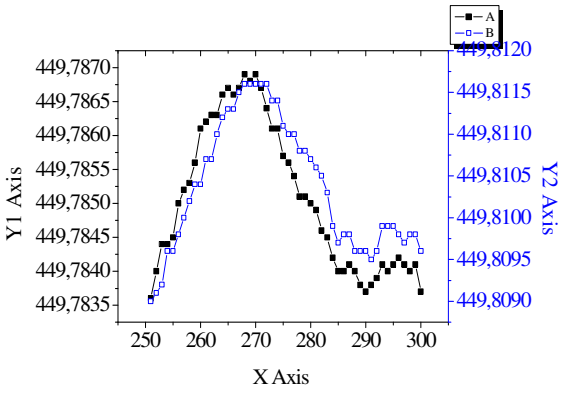

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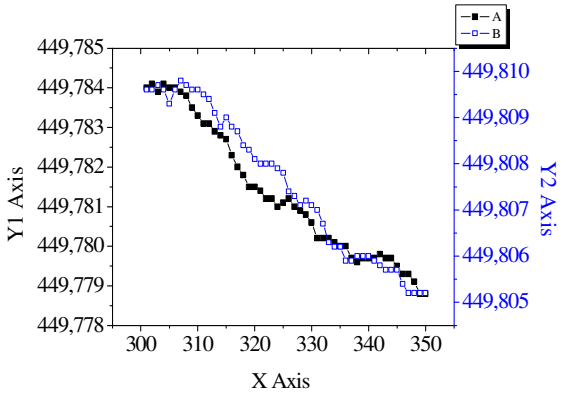
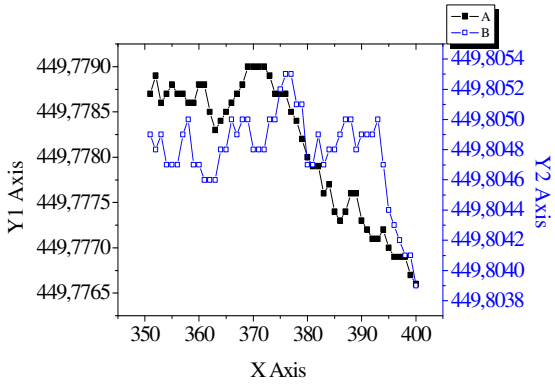


Figure 5.112



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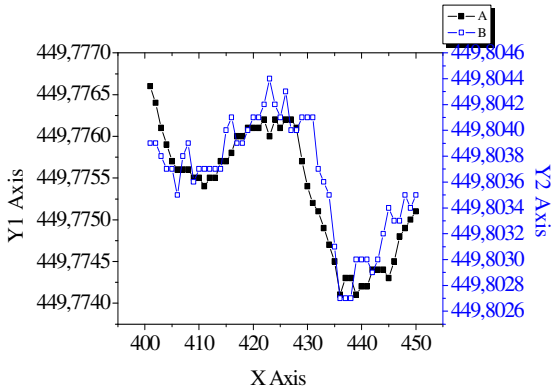


Figure 5.114

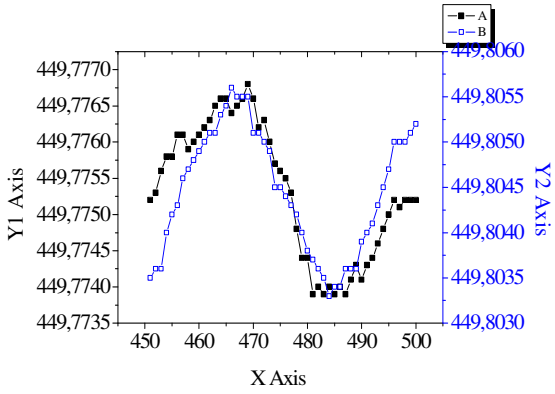
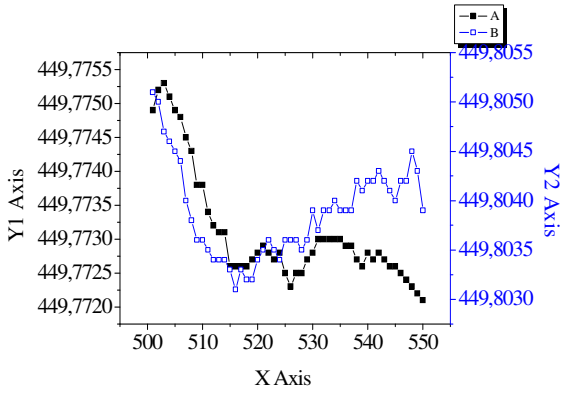


Figure 5.115



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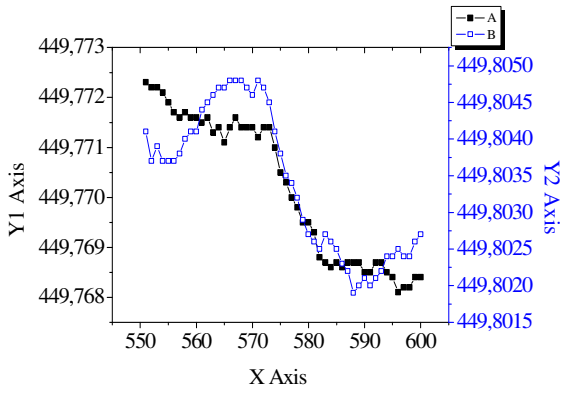
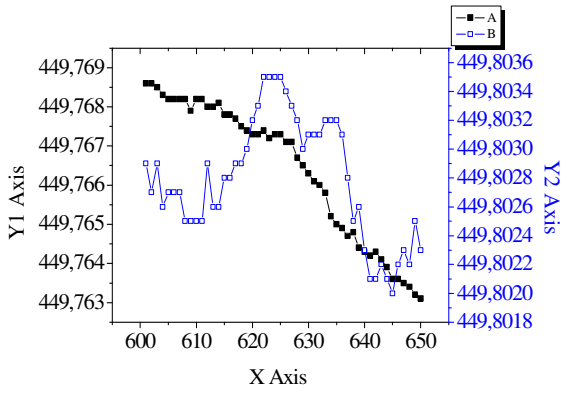


Figure 5.117



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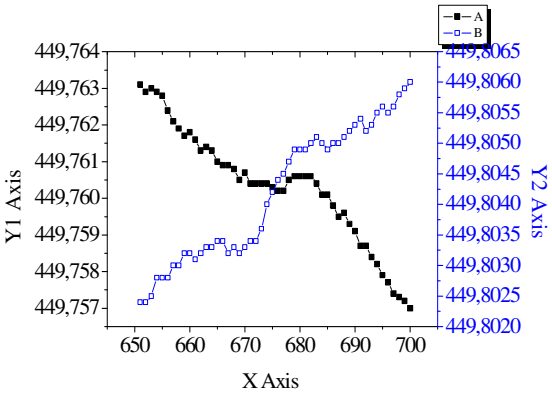

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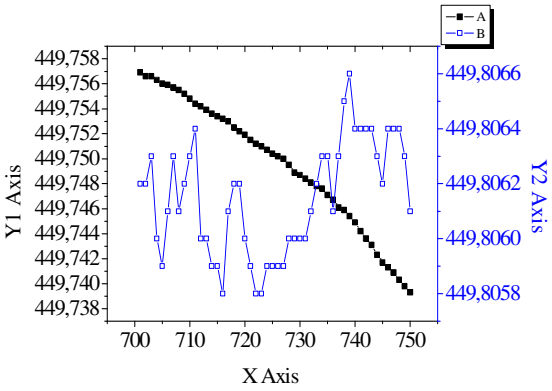


Figure 5.120

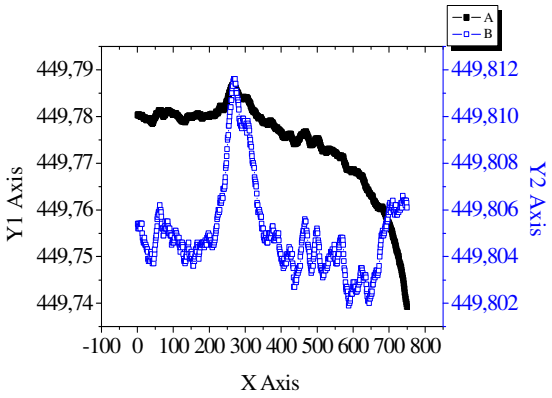
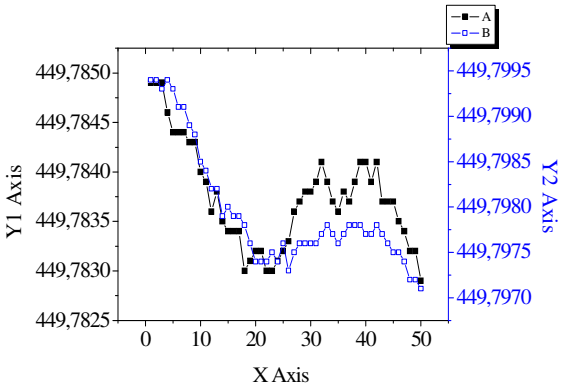


Figure 5.121

Blue line is fixed probe, Black line is moving probe.

Salt Bath at 450ºC all the probes are moving

For figures, 5.122-5.137 there are two Y-axes and one X-axis the different colors indicates different probes. Y-axis depends on the temperature and X- axis depends on the intervals. In figure 5.137 the full graph is shown, from figures 5.122 to 5.136 the full graph is split for better resolution



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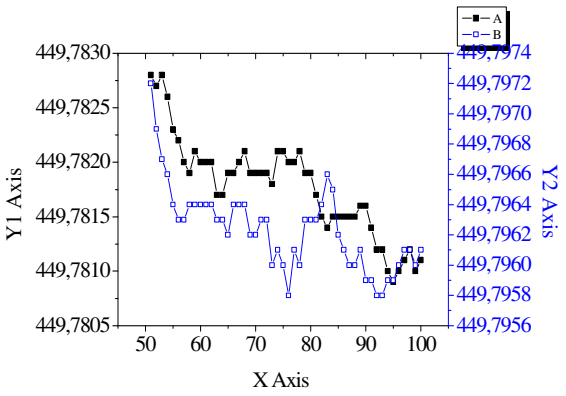

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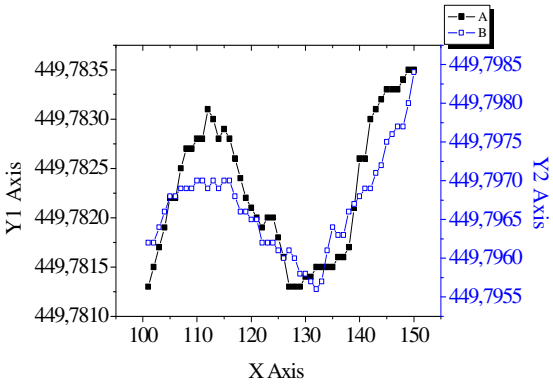

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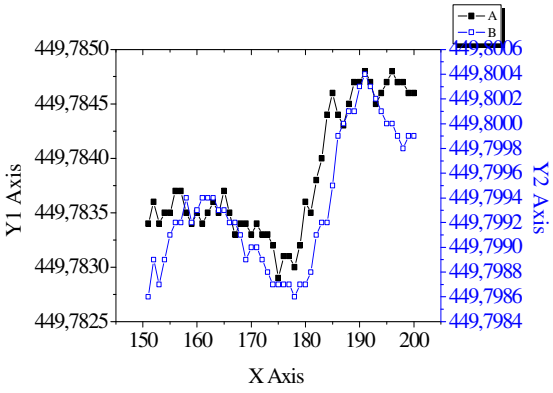

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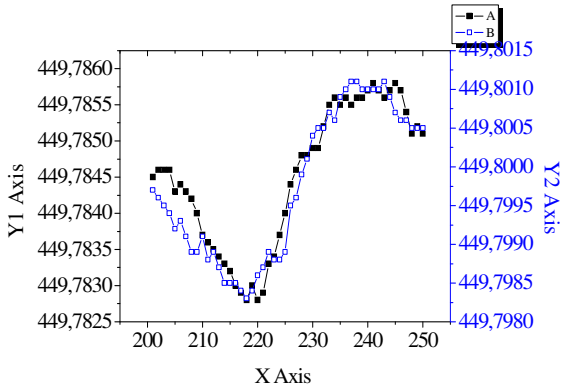


Figure 5.126

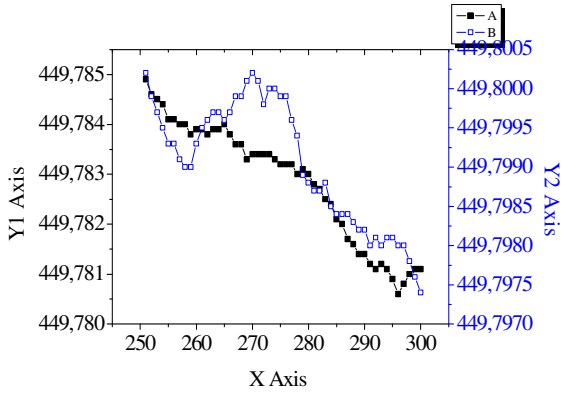


Figure 5.127

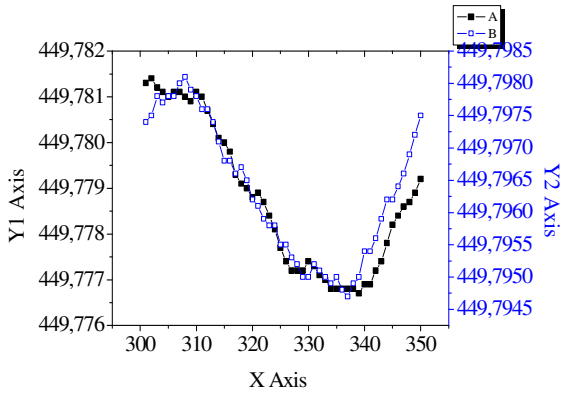


Figure 5.128

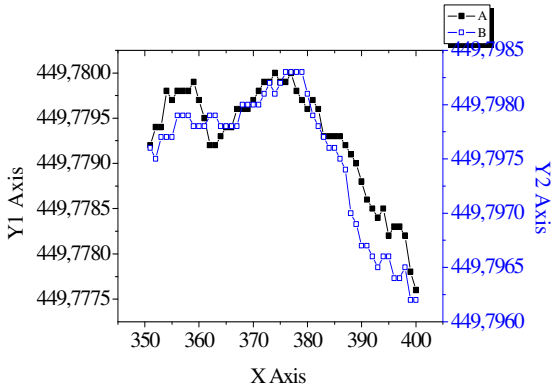


Figure 5.129

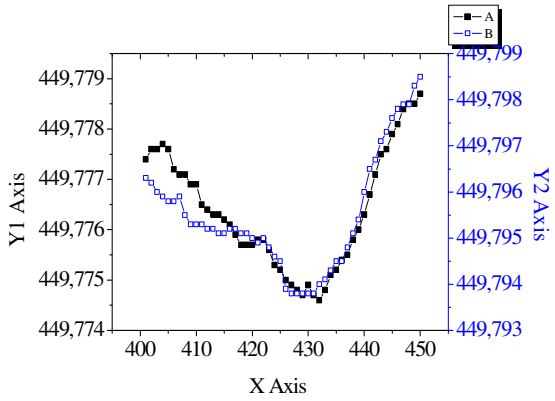


Figure 5.130

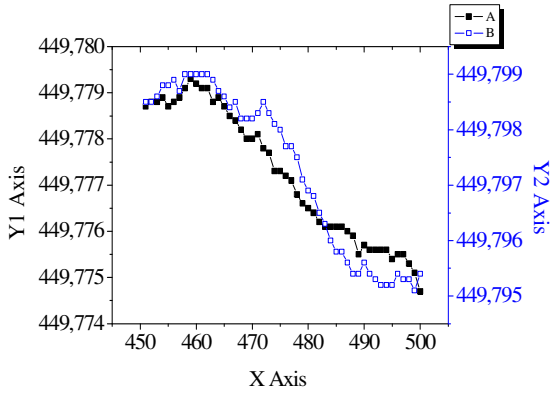


Figure 5.131

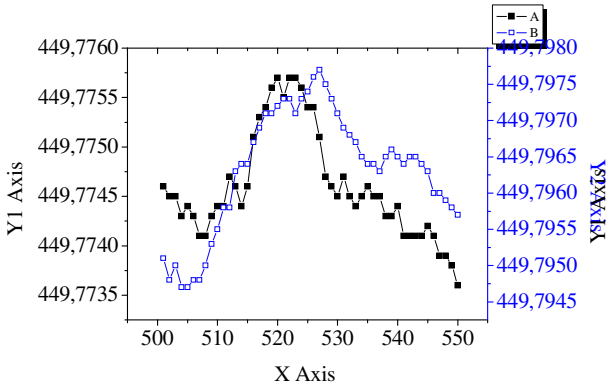
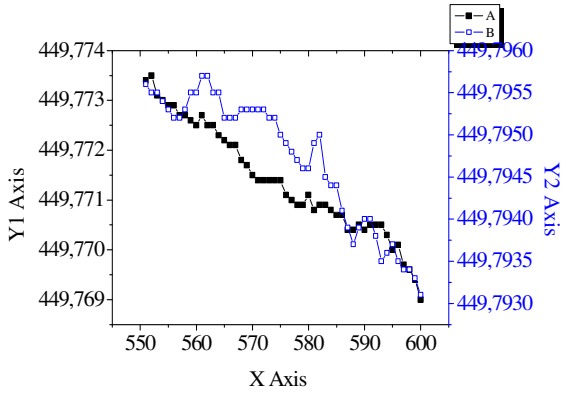


Figure 5.132



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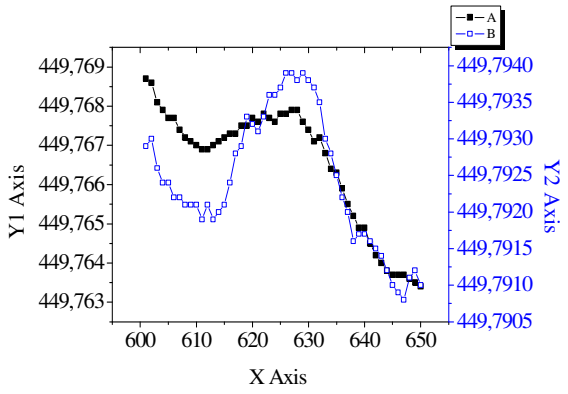

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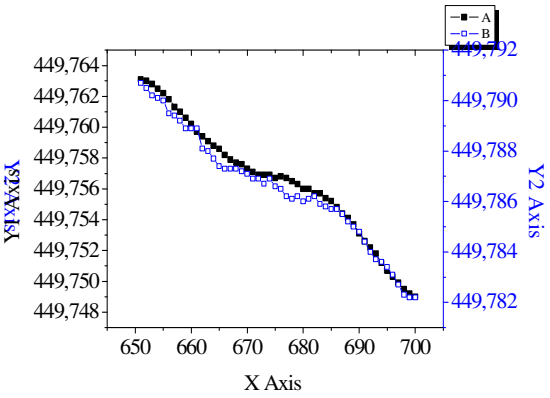

Figure 5.135

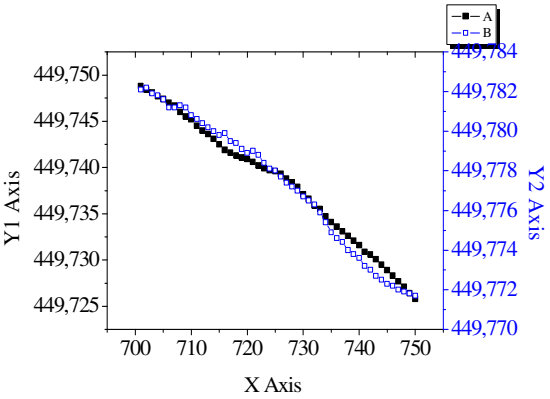

Figure 5.136

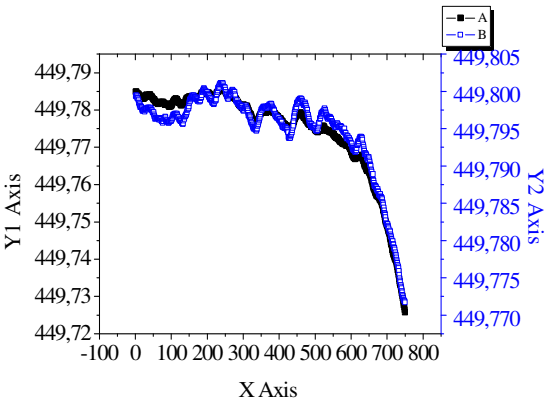

Figure 5.13

Salt baths;

Using salt as a substance means a high temperature is required, the system works in a limited area. Thus, there is only one axis labeled “Z" on the graph. From figures 5.14 to 5.136, there are always two lines on the graphs, this is because, there are two probes obtaining absolute temperatures at the same time interval; however, in figures 5.14-5.29, 5.46-5.57, 5.73-5.89,5.106-5.121, one probe is fixed at the bottom point and the other one is moving from the bottom point to the surface. The data shown in the figures are displayed in a 5mm interval.

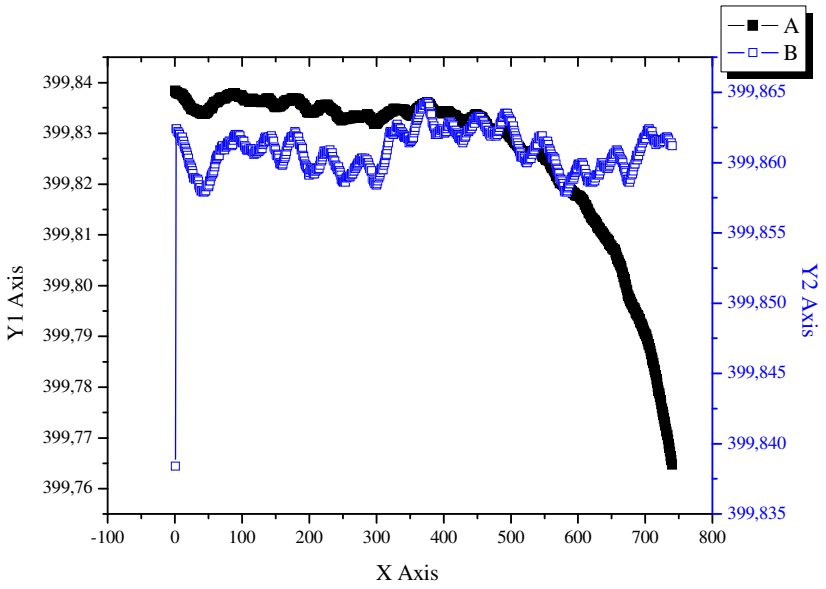

Figure 5.138 The Blue line is the moving probe and the black line is to be the fixed probe for 400ºC at the salt bath

The Change in the temperature for the blue line is about 5mºC; however, the change in the black line is about 60mºC between the maximum and minimum points. Although the salt bath system is a closed system, change in the temperature depends on the immersion of the probe for the bath. In addition to this

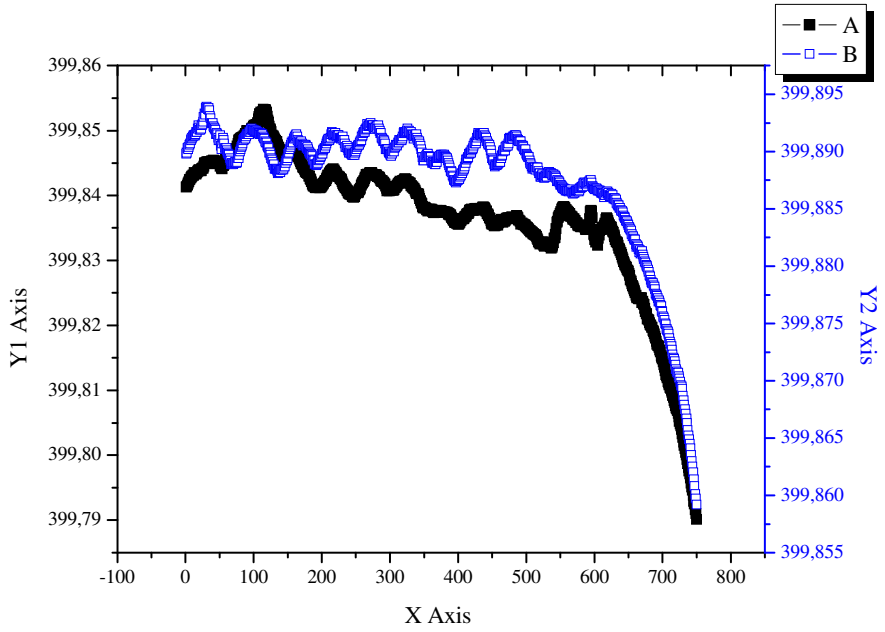

Figure 5.139 Both blue and black lines are moving probes at 400ºC at salt bath

When the two probes are moved at the same time, the change in the temperature according to the immersion is nearly the same 35mºC ~ 50mº. For these figures 5.136-5.137 is the all the data obtained on the same date, therefore the environmental conditions are the same for both situations. The change in temperature depends only on immersion of the probe. In figure 5.136 the fixed probe was immersed about 28 (cm) from the top of the bath and the fluctuation of this probe was 5 mºC which is also in the range of the specifications stated in the manual. According to this data, the probes, immersed 28 cm from the surface of the bath give better temperature stability.

6. CONCLUSION

A 3-D scanner device was designed and a mechanical platform in which two probes can be located and have the ability of three-dimension movement was constructed. These were used to find the temperature profile in 3-D of a water bath, oil and a salt bath. The scanning was computer controlled in order to remove human error in uncertainty calculations. During these studies it was found that homogenous locations of temperature can be achieved by using stepper motors and by moving these stepper motors in appropriate intervals. Three stepper motors controlled by computer, move the platform on three metric10 screw and two drawer rails. Open source code software, which will enable the computer to control these step motors was developed. With the help of this device the temperature distribution of Hart Scientific Baths was investigated. Owing to these graphs and figures, the baths' temperature stability could be compared with the manual specifications, at the points the manufacturers state are most stable in temperature. This 3-D scanner and these results are of significant value to those industrial labs working with such baths to reduce their measurement uncertainties.

APPENDİX A

Information about the tools that are used

BATHS

Hart alcohol-water bath 7037

Range	: –40°C to 110°C
Stability	: –40°C ±0.002°C 0°C ±0.001°C 25°C ±0.0005°C 100°C ±0.002°C
Uniformity	: ±0.002°C
Set-point Resolution	:0.01°C; high-resolution mode, 0.00007°C
Display Temp. Resolution	:0.01°C
Digital Setting Accuracy	: ±1°C
Digital Setting Repeatability	: ±0.01°C

Hart oil-bath

Range	: 20º- 300ºC
Stability	:±0.001 at 40ºC water ±0.003 at 100ºC oil ±0.005 at 300ºC oil
Uniformity	: 0.002 at 40ºC water ±0.004 at 100ºC oil ±0.012 at 300ºC oil
Set-point resolution	: 0.01°C; high-resolution mode, 0.00018°C
Display Temp. Resolution	:0.01ºC
Digital Setting Accuracy	:±1ºC
Digital setting Repeatability	:±0.02ºC

Hart salt-bath

Range	: 200ºC to 550ºC
Stability	: ±0.003 at 200ºC salt
	: ±0.010 at 550ºC salt
Uniformity	: ± 0.005 °C at 200 °C (salt)
	: ± 0.010 °C at 550 °C (salt)
Set-point resolution	: 0.01°C; high-resolution mode, 0.00018°C
Display Temp. Resolution	: 0.01ºC
Digital Setting Accuracy	: ±1ºC
Digital setting Repeatability	: ±0.01ºC

THERMOMETERS

Platinum Resistance Thermometers

Temperature Range	: -200ºC to 661ºC
R_{tp}	: 100Ω ±1Ω at 0.01ºC
Resistance RatioW (Ga)	: W (302.9146K) ≥1.11807 $\alpha \geq 0.003925$
Calibration Uncertainty	: ±0.006°C at –200°C
(k=2)	±0.004°C at 0°C
	±0.009°C at 420°C
	±0.014°C at 661°C
Short-term stability	: ±0.003ºC

Hart Super Thermometer

Resistance Measurement Range: 0 to 500kΩ

Resistance Ratio Accuracy :

0 to .25Ω input (1Ω refr, 10 mA) 0.00001Ω	0.000005Ω
0.25 to 4Ω input (1Ω refr, 10 mA) 40 ppm	20 ppm
2.5 to 40Ω input (10Ω refr, 3 mA) 20 ppm	5 ppm
0 to 25Ω input (100Ω refr, 1 mA) 0.0001Ω	0.000025Ω
25 to 400Ω input (100Ω refr, 1 mA) 4 ppm	1 ppm
400 to 1000Ω input (100Ω refr, 0.1 mA) 20 ppm	4 ppm
0 to 2.5 kΩ input (10 kΩ refr, 0.01 mA) 0.025Ω	0.012Ω

2.5 to 40 kΩ input (10 kΩ refr, 0.01 mA) 10 ppm	5 ppm
40 to 100 kΩ input (10 kΩ refr, 0.005 mA) 50 ppm	25 ppm
100 to 500 kΩ input (10 kΩ refr, 0.002 mA) 200 ppm	120 ppm

Resistance Accuracy

0 to .25Ω input (1Ω refr, 10 mA) 0.000025Ω	0.00001Ω
0.25 to 4Ω input (1Ω refr, 10 mA) 100 ppm	40 ppm
2.5 to 40Ω input 10Ω refr, 3 mA) 40 ppm	20 ppm
0 to 25Ω input (100Ω refr, 1 mA) 0.0002Ω	0.00015Ω
25 to 400Ω input (100Ω refr, 1 mA) 8 ppm	6 ppm
400 to 1000Ω input (100Ω refr, 0.1 mA) 25 ppm	10 ppm
0 to 2.5 kΩ input (10 kΩ refr, 0.01 mA) 0.05Ω	0.025Ω
2.5 to 40 kΩ input (10 kΩ refr, 0.01 mA) 20 ppm	10 ppm
40 to 100 kΩ input (10 kΩ refr, 0.005 mA) 60 ppm	30 ppm
100 to 500 kΩ input (10 kΩ refr, 0.002 mA) 200 ppm	120 ppm

Minumum sample period : 2 seconds

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