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ABSTRACT

MEASUREMENT OF VELOCITY OF A HIGH SPEED WATERJET

by
Chang-Hsin Yu

In order to maximum the productivity of water jet cutting and cleaning. The determination of the particle velocities at different conditions of water jet formation is essential to the establishment of a prediction model of the cutting results.

The Study is Intended to develop an interface between Laser Transit Anemometer (LTA) and IBM PC for velocity field measurement of the jet by automation of technology design. To achieve this, a turbo basic program is developed to link LTA, counter processor, NIC-320 nicolet oscilloscope and IBM PC together for improve the efficiency and quality of velocity's measurement of the jet.

Because of computer speed, memory, and computational capabilities, a new system is developed by used LTA to measure the velocities of the particles entrained in the water jet automatically and the technique is validated. The result compare with manual measurement that increase the efficiency and accuracy of water jet velocity measurement along the down stream by 80%.

MEASUREMENT OF VELOCITY OF A HIGH SPEED WATERJET

by
Chang-Hsin Yu

A Thesis
Submitted to the Faculty of
New Jersey Institute of Technology
in Partial Fulfillment of the Requirements for the Degree of
Master of Science in Mechanical Engineering

Department of Mechanical and Industrial Engineering

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MEASUREMENT OF VELOCITY OF A HIGH SPEED WATERJET

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This thesis is dedicated to
my parents

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CHAPTER 1

INTRODUCTION

Water jet is one of the best flexible manufacturing and cleaning tool used in industrial application. It can provide significant gains in productivity material utilization and quality of finishing. The pure water is pressurized up to 325 MPA and expelled through a sapphire orifice to form a coherent and high velocity water jet as shown in Figure 1.1.

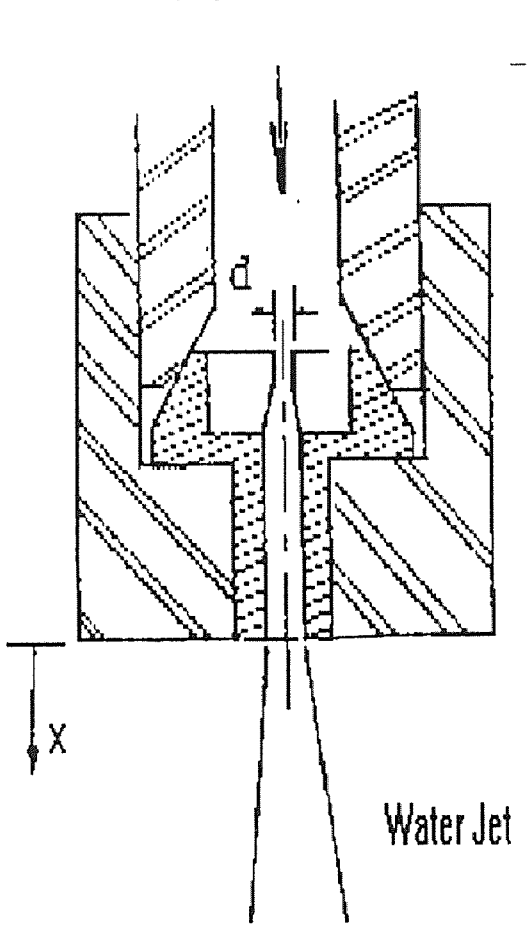


Figure 1.1 Schematic of Sapphire Nozzle With Water Flow

In abrasive water jet cutting technology, the abrasive is entrained into the down stream of high speed water jet then accelerated and guided by the carbide tube to form an abrasive water jet. Here, part of the waterjet's momentum is transferred to the abrasives, whose velocities are abruptly increased. As a result, a high velocity stream of abrasives is formed which performs the cutting process as show in Figure 1.2.

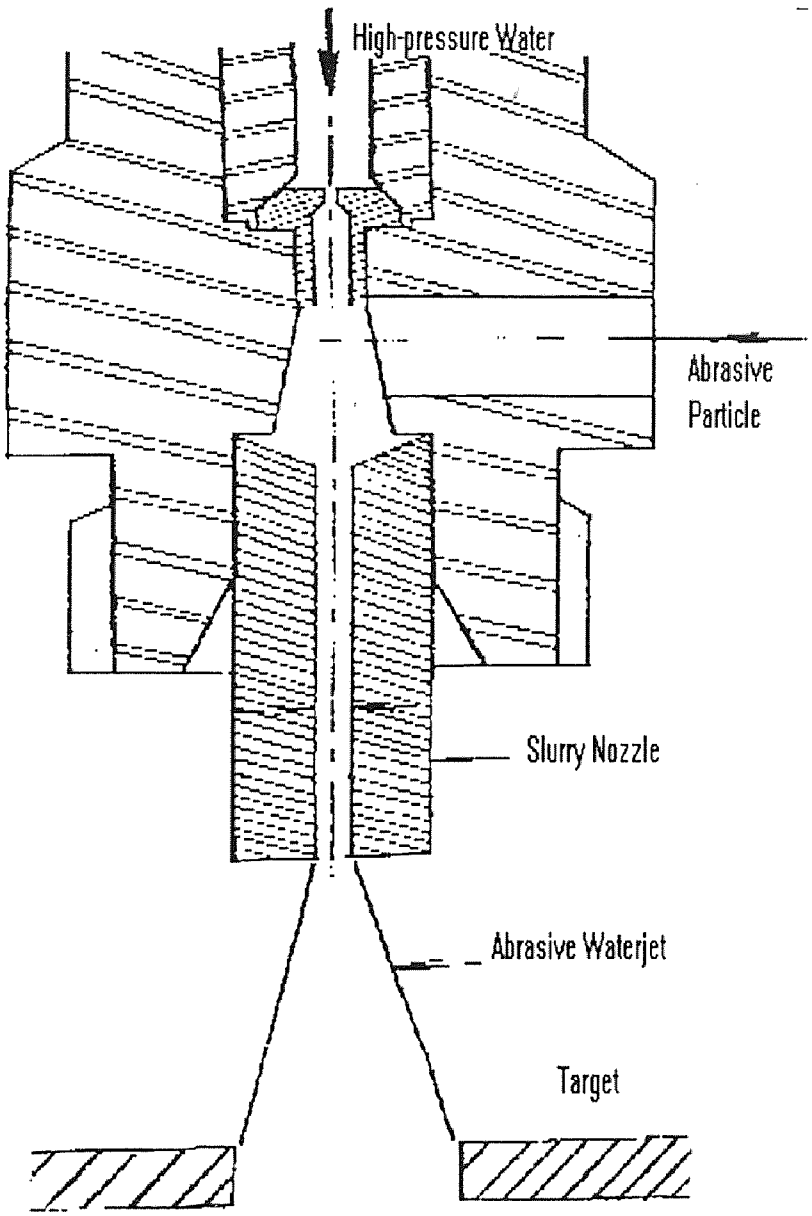


Figure 1.2 Schematic of The Assembly For The AWJ Formation

In order to maximumize the productivity of waterjet cutting and cleaning, prediction of the exact natures of the erosion mechanism is required. The study of surface erosion upon impingement of the abrasive water jet involved determining the fluid conditions, the direction and the velocities of particles striking the surface; then calculating the amount of surface material removed by the jet. Therefore, it is essential to determine the particle velocities at different conditions of water jet formation to the establishment of the prediction model of the cutting results.

The objective of this study is to find a reliable and automatic technique that allows us to measure the velocity field of the jet under different diameters of the sapphire nozzle. A special setup and measurement procedure has been developed by using Laser Transit Anemometer (LTA) in order to specifically measure the velocities of particles entrained in the desired region of the jet. The developed setup enabled us to identify the velocity's field of the jet accurately and automatically.

CHAPTER 2

SURVEY OF WATERJET CUTTING TECHNOLOGY

In recent years, waterjet cuttings have been introduced in a number of industrial applications. The special features of this technology provide an effective new machining method for material shaping, particularly for materials that can not be shaped though the use of conventional cutting tools. Such as glass plates.

2.1 Development of Waterjet Cutting Technology

In 1852, the earliest application of waterjet was used for Hydraulic mining of gravel banks in Californian and the technique was applied later both in Californian and Alaskan gold mines.

In the late 1950's, waterjets were being used in Russia for the mining coal because of their safety, particularly, the elimination of the hazardous, frictional ignition of methane. But the application presented low jet pressure (300 bar) with high water flow (10-50 lb/s).

In 1968 Dr. Norman Franz filed the first patents for high pressure water for cutting of materials and subsequentially introduced the application in 1971. It remained a questionable technique until the early 1980's. During the same year, McCartney installed the world's first waterjet cutting work cell in Alton Boxboard Co. to cut 3/8 inch pressed board. After this most than 1,000 units have been installed by various manufacturers worldwide for use in cutting and shaping various soft materials.

Materials one was able to cut with the pure waterjet, until recently, were limited to the soft variety because of the relatively low shear strength and, thus, it prohibited use as a generalized tool. The advent of abrasive cutting in the early 80's expended the potential

of the process to include every known material. The abrasive waterjet, a pure waterjet fed with abrasives, become powerful to allow the generalization that any material can be cut.

The timing of this development coincided conveniently with two other influential trends. The first was the maturing of the Robotics industry. The second was the almost compelling influence toward productivity, at the conclusion of the world wide recession. These factors interacted to revitalize the waterjet cutting technology.

2.2 Mechanism of Waterjet Cutting

The waterjet cutting system (Figure 2.1) includes the following units :

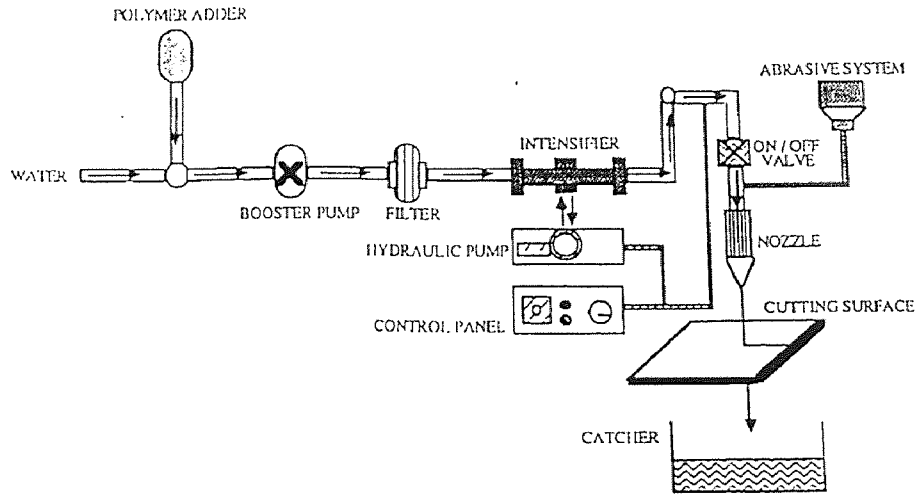


Figure 2.1 Basic Components of The Waterjet System.

1. Water preparation unit:

   This unit continuously feeds pure water and pressurizes the water at the required high pressures. The components are the booster pump, filter, softener, prime mover, intensifier, accumulator, and control and safety instrument.

2. Booster pump:

   The water pumps into a low pressure water circuit (1.25Mpa) to ensure continuous flow into the high pressure cylinder, where it is charged into the system. Low pressure filters (1-10 microns) and the softener is used to soften the water and to remove the iron and calcium dissolved solids.

3. Intensifier:

   It is a sample hydraulically driven reciprocating plunger pump. Low pressure hydraulic oil alternately applied to each side of a large piston causing it to move back and forth. The oil is supplied by a variable volume pressure compensated pump driven by an electric motor. The reciprocating motion is achieved through directional valves. The movement of the large piston drives the small diameter high pressure plunger that acts as small high pressure cylinders.

4. Control and safety instruments:

   The high pressure water discharged to an accumulator from both sides of the intensifier, because the water pressure up to 345 Mpa is not uniformly at all positions of intensifier. An accumulator provides a uniformly discharge and flow. For recording oil and water pressure two pressure gauges are mounted in the oil and water lines as the safety device.

5. High pressure water distribution system:

   The high pressure water output of the accumulator, is conveyed to the work station through a series of pipes, swivels, flexible joints and fittings, the pressure drop can be calculated at the basis on the number of joints, elbows and the total pipe length

6. Work station:

   It consists of the following major component.

7. Nozzle assembly:

   Here water pressure head convert into kinetic energy. The high pressure from the water distribution line passes though sapphire nozzle and accelerates to a velocity of

600-800 m/sec. In abrasive waterjet case, abrasive enters from the side port, after the sapphire nozzle, mixed in the carbide nozzles, accelerated and energy transformation takes place.

8. Abrasive feeder:

   This unit continuous deliver abrasive into the nozzle assembly at a controlled rate. A feed hopper stores 10-180 kg of abrasive and an electromagnetic vibrator tray requital the flow of abrasive from the hopper. The suction created in the nozzle assembly draws abrasive from the vibrator tray.

9. Robots and CNC controlled:

   The unit use a computer to load NC program to control water and abrasive flow as well as robot movement. CNC machine codes are used to write the program.

2.3 Advantages of Waterjet Cutting

- Minimal or no dust.
- Available increased cutting speeds.
- Multidirectional cutting.
- No dulling of the cutting tool.
- No thermal or deformation stresses.
- Reduced operation costs result from lower maintenance and downtime.
- Most of the heat generated by the cutting process is carried away by the jet. Material structure and mechanical properties of the material remain unchanged. Fusing of the material is eliminated.
- It offers increased cutting efficiency over conventional methods.

2.4 Application of Waterjet Cutting

The applications of jet cutting can be broadly subdivided into two main categories: destructive applications and precision cutting. The main destructive applications are

breaking and removal of rock, concert, coal, or other mineral and cleaning of metallic or other surfaces of unwanted deposit. The objective is to remove the maximum amount of material with minimal consideration of the quality of the cutting edge. Precision cutting applications use waterjet to replace a conventional cutting or piercing tool such as a saw, knife or drill or even in the medical field, a hypodermic needle. It's main applications are used in factories and have been continually developed during the past decade. The difference between jet cleaning and cutting applications is that for jet cleaning the energy given to the jet being evenly spread over a limited area, in jet cutting the energy is concentrated in a relatively small area to give an efficient narrow cut.

CHAPTER 3

OBJECTIVE OF THE STUDY

The study is intended to bridge the gap between Laser Transit Anemometer (LTA) and IBM PC for velocity field measurement of the jet by automation of the technology design. To achieve this, a turbo basic program is developed to link LTA, counter processor, NIC-320 nicolet oscilloscope and IBM PC together for improve the efficiency and quality of velocity's measurement of the jet. In order to provide more information for understanding of fluid dynamic characteristics of the jet, its structure and the determination of its corrosive properties.

The works are including :

1. Investigate the system we already have, manual velocities measurement system.

- To accomplish this, run though the manual measurement system to find out the way of efficiency, accuracy and automatic measurement.

2. To develop a computer program that offers the following functions :

- The program control NIC-320 Nicolet oscilloscope though RS-232 cable by IBM PC downloads dates automatically.
- The program will define and download the range according to initial input both automatic and manual.
- The program calculate the download dates and show the velocities reading automatically.

CHAPER 4

THEORY OF LASER TRANSIT ANEMOMETER (LTA)

4.1 Basic Concepts

A laser transit anemometer (LTA) provides a method for obtaining flow field information. Particles entrained in the flow provide scattering centers for the incident light. There are two common techniques for optically coding the measurement region. The laser Doppler anemometer (LTD) employs a sinousidally varying fringe pattern.[1-3] Knowledge of the fringe spacing and the detected frequency of particles traversing the measurement region permits the determination of the velocity component normal to the fringes. Another technique for encoding the measurement region uses closely spaced spots, where the flow velocity component that is parallel to the axis connecting the spots is obtained from the time-of-flight (TOF) of the particles traversing the two spots. The distance between the two foci is 300-600μm which is far greater than the distance between the interference fringes (which are of the order lum Figure 4.1).

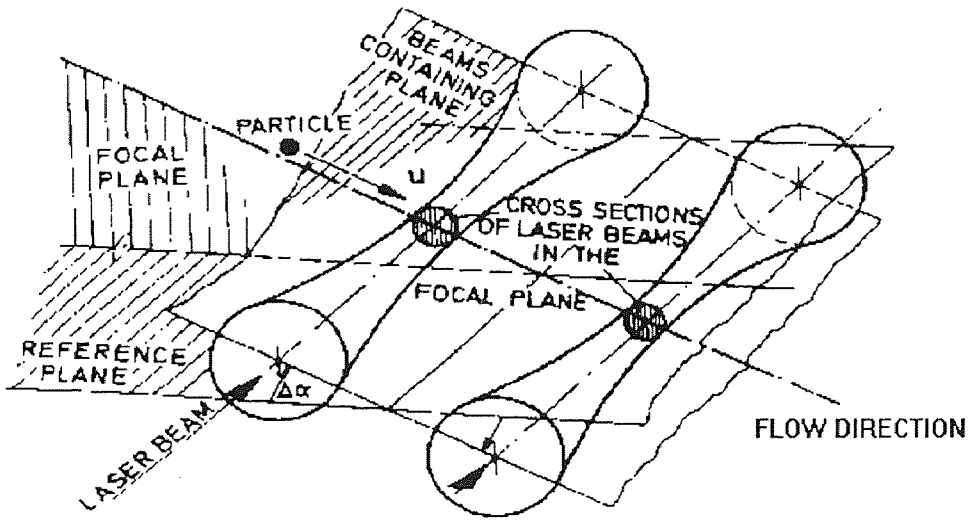


Figure 4.1 Sketch of the LTA Measuring

The signal obtained from a TOF system consists of two noisy Gaussian shaped pulses separated by the transit time of a particle traversing the two light spots in the measurement region. An estimate of the peak to peak time of flight and knowledge of the spot spacing then yields the particle velocity component along the axis of the two spots. A good method of estimating the time of flight for noisy pulses can be obtained by transforming the unipolar pulse into a bipolar pulse. The zero crossings of the bipolar pulses yield the estimated time of flight. The transformation from a unipolar to a bipolar pulse ideally should not introduce additional noise to the signal. Unfortunately, most particles do not travel directly from one focus to the other focus. There are five possible cases for the motion of the particles as shown in Figure A.1 and how to get correct signal is discussed in appendix A. For homogeneous turbulence, if the distance between the two foci, L is small enough the turbulence parameters within a distance 2L can be considered as constant. The average distance between particles is assumed to be far greater than L. The direction of flow is always from one focus towards the other focus.[6-7]

4.2 Manual Measurement

Axial waterjet velocity measurement is using a #10 sapphire under 50,000 Psi pressure, stands off distance from 0.5mm, 2mm, 6mm, 18mm, 54mm, 105mm, to 155mm respectively. The procedures are as following :

1. Attach #10 sapphire to nozzle body and check the jet concentration at low pressure.
2. Two concentrated laser beams are focused on the low pressure jet, a 10X magnifying glass put behind the jet in order to observe the laser light and the jet. Use the hand wheel on the control panel to align the jet at the center with the two parallel laser beams.
3. Connect LTA, counter, oscilloscope and IBM PC then tune on the power.

4. Start NC program that loads in waterjet work cell at 5,000 Psi pressure for 300 sec without robot movement.
5. Set counter at transit mode operating position, makes sure the digital low pass is higher than digital high pass. First selects width range between low pass and high pass then reduced the low pass and increases high pass in order to catch the right signal. The scale factor selected at 8396. The threshold window, amplifier gain and voltage reduction buttons are released.
6. At the same time, digital velocity display windows on the counter show the velocity in m/sec continuously . It ranges from 200m/sec to 4000m/s.
7. Connect counter output to oscilloscope, active one channel, select time base at 50n sec and channel voltage set at 300mv. Choose trigger at the normal operating mode.
8. Press the hold last and let the oscilloscope display the data frozen in memory, Define the signal, active Henry (file transfer software for Nicolet oscilloscopes) loaded in IBM PC. Transfer data from oscilloscopes to PC and convert into a format used by Lotus. A Macro is included with the Henry software reproduce the wave form and display on PC screen to fine the time between two peaks.
9. The distance between two laser beams is 449 μm. This distance divides time that pinned at (8) came out the speed by m/sec.
10. When same particle passes though two laser beams, two peaks will be detect by the oscilloscope on display window. If two peaks are above 150 mv and all other peaks are below ±50 mv, then the signals are considered as satisfactory.
11. After collecting 30 set dates at one stand off distance, use the statistically package to analyze in order to give normal velocity distribution and arithmetic mean.
12. Using Z direction switch on the control panel, the nozzle is moved to second stand off distance.
13. Repeat the above steps (2) though (13). All results are in APPENDIX D.

4.3 Automatic Measurement

The manual measurement described above, when compared with recorded velocity reading from counter display window by handwriting is more reliable and accurately. When reading from the counter, the velocities range are too wide and mistake can be involved. But from defines the signal, download the dates, to analyze the dates still not efficiency. In this study automatic measurement took all steps in one try using RS232 interface that was built into both the Nic-320 oscilloscope and the IBM PC and connected with RS232 cable. This, in turn, was then developed specially in a Turbo Basic computer program, which when load into the IBM PC automatically controlled the above procedure. The complete description is given later in program for automatic signal identification section.

CHAPTER 5

EXPERIMENTAL FACILITIES

5.1 Laser Transit Anemometer (LTA)

The setup of the optical head is indicated in Figure 5.1. The beam splitter BS1 receives the source light and creates two beams. The beam plane formed by these beams can be rotated by two polarizes P1 and P2 to ensure its coincidence with the direction of the flight of particle. The two beams are focused by the lens system to form the measuring volume. Additionally the image of two focal points is received by the same lens system and is transmitted via the mirrors M1 and M2 to the beam splitter BS2 The scattered light, generated by a particle passing through the measuring volumes detected and converted to the voltage signals by the photo multiplier PM. Thus, the signals are transmitted to the data processing system for the determination the particle velocity by measuring the time period between the signals, which are indicated at Figure 5.2.

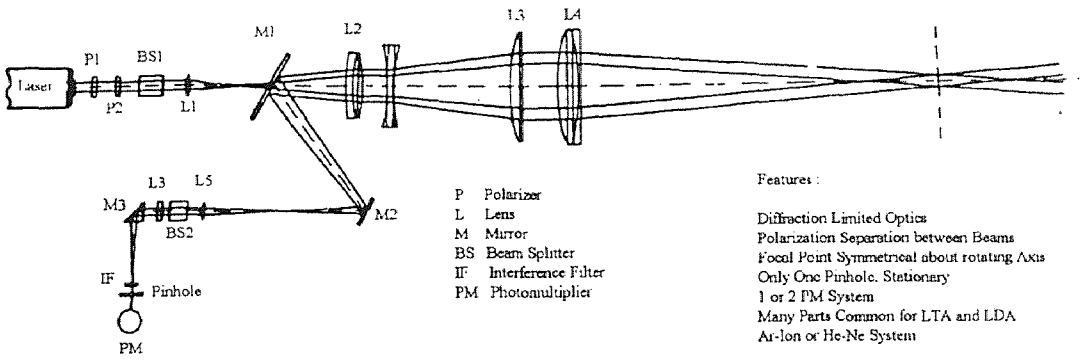


Figure 5.1 Schematic of LTA Operation

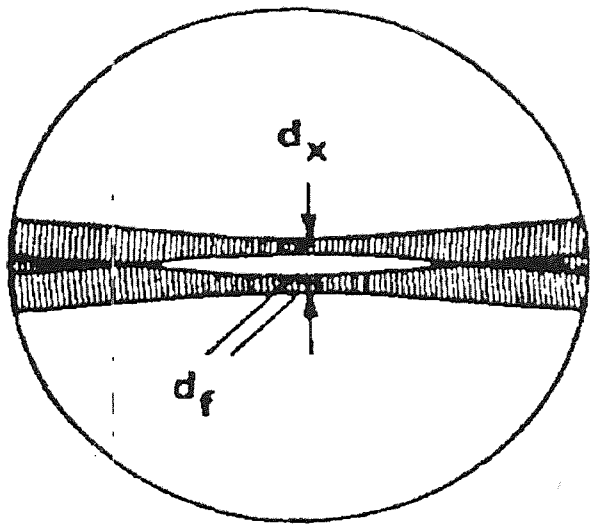


Figure 5.2 Measuring Volume of LTA

5.2 Counter Processor

The 55L90A counter processor was used to receive the voltage signals from LTA photo multiplier in the optical head and conveys these signals in analog form to the oscilloscope and though RS232 cable to IBM PC. It also measures the time between two successive signals. In our study, the calibration factor is selected at 8369. The thumb wheel switch selected at 1, the functions set at transit mode.

5.3 Nic-320 Nicolet Oscilloscope

A Nicolet 2-channel digital oscilloscope was used for this study. It offers the valuable functions as following:

Display:	5-inch, high definition.
Save Reference:	Save one reference signal per channel.
Trigger	
a. Modes	Auto/Norm
b. Coupling:	AC/DC (AC roll-off at 1.6 Hz)
c. Slop	+,-

d. Source	Channel A, Channel B, External
Numeric	
a. YT Display Mode:	Time and voltage plus channel identifier.
b. XY Display mode:	X-volts and Y-volts plus channel identifier.
Expansion:	Cursor-interactive
a. YT (Horizontal) :	Up to X400
b. YT (Vertical) :	Up to X10
c. XY (Both Axes) :	Up to X10
Bubble Memory	
a. Bubble Memory Type :	One megabit bubble memory cassette.
b. Capacity/Cassette :	21-4K pt wave forms and 20 linked functions.
c. Write protection :	Manual
d. Autocycle :	Available though function menu.
Digital I/O :	
a. Interfaces Available	IEEE-488 (GPIB),RS-232C, Digital plotter controller (RS-232, IEEE-488)
b. IEEE-488 (GPIB) :	Bi-direct., upto 15K bytes/sec output ASCII or binary.
c. RS-232C :	Bi-direct., upto 19.200 baud, ASCII or printable binary
d. Transfer Times (.min., 4K)	
1. GPIB Binary output :	1.5 seconds
2. RS-232C Binary output:	18 seconds

5.4 IBM PC

The function of the computer in our study involved the following operations :

1. Sending "hold next" commands to oscilloscope in order to frozen the signal that the next trigger generate then transfer these dates back to PC. (When transfer dates from oscilloscope must in "hold last" position)
2. Find the two peaks and compare them with initial input range value. If in the satisfy range, download the dates. If not, ignore the dates. The procedure will continuous untill it meet the initial setup.
3. At "find range" position described above. Each transfer contains 4K dates, in RS-232C binary output need 18 sec to complete; then compare with the initial range value which should be around 20 sec.
4. Later at "test" position PC requires time to calculate between two satisfy signal and to converted to velocities output file.
5. In our measurement only, RS-232 cable connecting between PC and oscilloscope, every step fixed to finish one by one.
6. An IBM or comparable PC 386DX 33 MHz with math co-processors or upgrade are recommended.

5.5 Connecting Cable

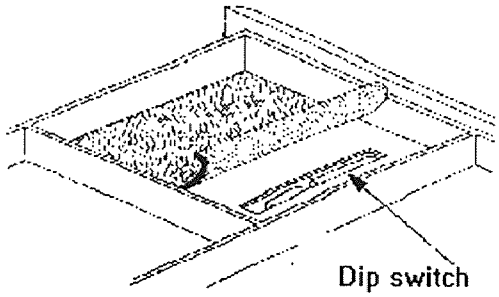
The RS-323C cable and connector are using in this study, have a hardware set up as following :

1. 320 oscilloscope dip switch setting

   Several manual switch settings must be made before the 320's RS-232 interface can be put into service. These settings determine the baud rate, delimiter, and parity. The 320's interface setting must be compatible with the specifications of the connected device. The RS-232 switch is located under the 320's top lip in the right real compartment Lift the foam piece to access the switch. Figure 5.3 and Tables 5.1 through 5.3 for the RS-232 switch identifications and setting.

2. Cabling

The 320's RS-232 port is configured as a data terminal device (output is pin 2, input is pin 3) Direct cable connection to data communication ports can be done via a standard RS-232 cable. The RS-232 connector on the rear of the 320's is a standard 25 pin, D sub miniature rectangular connector. Standard RS-232 mating connectors are used. Hardware handshaking is accomplished on the 320's by connecting pin 5 (clear to sent) to IBM PC's pin 4 (request to send).



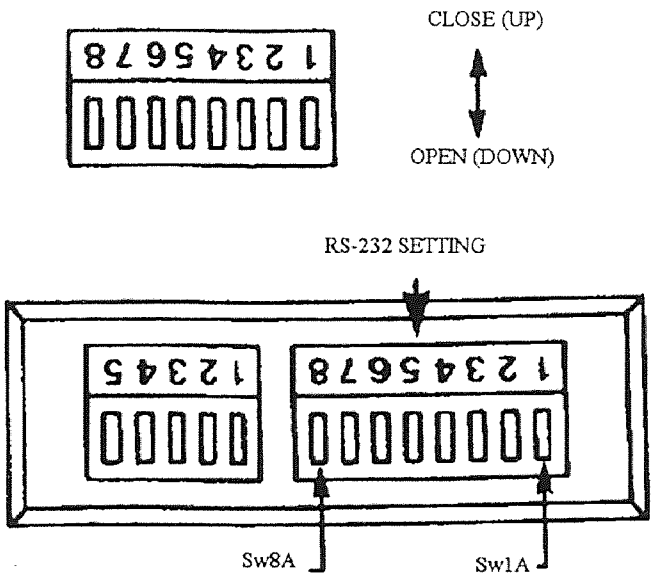


Figure 5.3 RS-232 Switch

5.6 Table of RS-232 Switch Identifications and Setting

Table 5.1 RS-232 Baud Rate

Baud Rate	Sw1A	Sw2A	Sw3A
110	closed	closed	closed
300	open	closed	closed
600	closed	open	closed
1200	open	open	closed
2400	closed	closed	open
4800	open	closed	open
9600	closed	open	open
19200	open	0pen	open

Table 5.2 RS-232 Command Delimiter

Command Delimiter	Sw4A	Sw5a
Carriage Return	closed	closed
Linefeed	open	closed
Carriage Return/LF	open	open

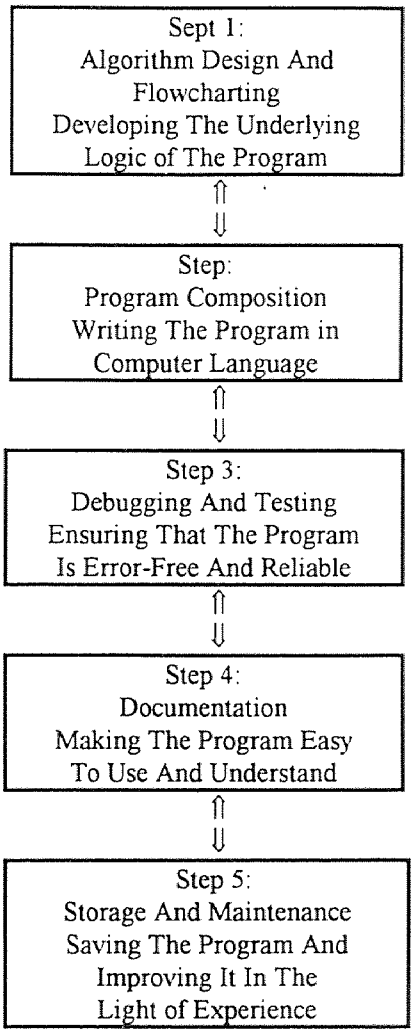
Table 5.3 RS-232 Parity

Parity	Sw6A	Sw7A
off	-	closed
odd	open	open
even	closed	open

CHAPTER 6

PROGRAM FOR AUTOMATIC SIGNAL IDENTIFICATION

Although writing a program is obviously of critical importance in our study, it is but one step in the overall development of high-quality software. The figure shown below delineates the five steps that constitute the entire process on this section by using Turbo Basic computer language.



The two-way arrows indicate the first four steps can be improved in the light experience.

But before the process can even begin, there is the preliminary step of problem definition and analysis. It includes:

1. Identifying the measurement problem and determining the solution technique.
2. Specifying the objectives we want to accomplish with the software

6.1 Identifying the Measurement Problem and Determining the Solution Technique

In this study the measuring system, which included a Laser Transit Anemometer(LTA), a Counter Processor(Dantec55L90A) was developed by Dantec Electronic Co., Nicolet Model NIC-320 Digital Oscilloscope, developed by Nicolet Instrument Corporation and an IBM comparable PC. The LTA beam splatter creates two beams that are focused by a lens system to form a measuring volume. The back scattered light from the particles passing through the foci was detected and converted to voltage signal by photo multiplier. The counter processor receives the voltage signals and computed it, and then the velocity values are continuously displayed on the counter screen. During the same time the signal output from Counter to NIC-320 oscilloscope will be stored and then the RS232 cable used to connect IBM PC for download stored data and to analyze velocity frequency distribution.

The velocity reading can obtained in two ways. First, after successful setup the output velocity reading will continuos display on the Counter screen, However, velocities renege that are too large, it from 200 m/sec to 2000 m/sec, also the readings have to recourse down manually. This is why it not used in this study. Second, download the signal from oscilloscope by IBM PC and analyze the velocity. This will increase the accurately but still can't be fully automated and normally one stand-off distance for thirty sample collatings and analysis will need more than eight hours to be completed. This is the main reason this program has been writing. In section 4 the theory of velocity measurement when signals get into oscilloscope, if the same particle passing through two foci's points, two pulses will be generate on oscilloscope screen. By measure the time

between two pulses devised by distance which two foci point will attend the velocity reading. Because both in IBM PC and NIC-320 oscilloscope own the built in RS-232 interface, each only needs a RS-232 cable to connect to each other and programming IBM PC to control NIC-320 oscilloscope download signals, to define the right signals, and to analyze the signals. It is the solution for efficiency and accuracy velocity measurement.

6.2 Specifying the Objectives We Want to Accomplish with the Software

The program can control oscilloscope download, define and analyze signals then converted to velocity dates and save in an output file.

6.3 Program Processing

6.3.1 Sept 1 Algorithm Design and Flowcharting Developing the Underlying Logic of the Program

The works following the flowchart (from Figure B-1 through Figure B-5 in APPENDIX B) structure divided the program into a main program and several sub programs such as subtest, subsetup, subdownload, subfindrangr, subconfigmenu, subgetint, subgetread. These sub programs are linked by the main program, when every time measurement start. First you will get the main window. In this main window is an on screen menu which can help the beginner to operate the system, according to they need. The functions of each sub program are listed below.

Subconfigmenu:	According to difference PC or dates transfer speed. The baud rate, parity bite, PC port will be defined.
Subsetup:	Initial value input.
Subtestrange:	Logically defining the two peaks of signal and find the range.

Subtest:	It operated both in initial data value and the data from subtestrange. Calculate between two peaks, and convert to velocity output file.
Subdownload:	It transfers dates in two ways, one is each time 4k the other way is dates from subfindrange each time data contain much less than 4K.
Subgetint:	Get the setup file or input dates that in program as initial value.
Subgetread:	Set horizontal and vertical range.

6.3.2 Step 2 Program Composition Writing the Program in Computer Language

A Turbo Basic program is listed in APPENDIX C.

6.3.3 Step 3 Debugging and Testing Ensuring that the Program is Error-Free and Reliable

- The program is debugging by using a compiler in Turbo Basic that proves the program is error-free and reliable.
- When loading the program on difference PC's, the band rate, parity bite and communication port selections are required in order to running the system without error.
- Cabling and RS-232 hardware handshaking are described at Chpter 5.

6.3.4 Sept 4 Documentation Making the Program Easy to Use and Understand

The program is designed in such a way to use windows to display each step menu on screen. The user operated each function according his/her wish. It is easy to use and understand.

6.3.5 Sept 5 Storage and Maintenance Saving the Program and Improving it in the Light of Experience

The program saves in two kinds of formats, BAS file and EXE file. The EXE file is unchangeable, it operating object, avoid the beginner damaging the program through errors, improved the program by change BAS file and creates the new EXE file.

CHAPTER 7

EXPERIMENTAL TECHNIQUES

Some small detail involved in our experiment that may effect the measurement deep is described below.

7.1 Instrument Setup

- Check every connection jack, in case of loosing and error connected.
- Cabling is every importance in this work. The detail is in Chapter 5.5
- Initial configuration setup for computer side should sleet the corrected input output port. The baud rate and Parity bite should match with oscilloscope setup.
- The oscilloscope setups in our study are using 9600 baud rate and parities bit none. The switch's positions of oscilloscope are described in Chapter 5.

The block diagram Figure 7.1 was shown below. The two way arrow indicate the PC send command and receive dates from oscilloscope by RS-232 cable.

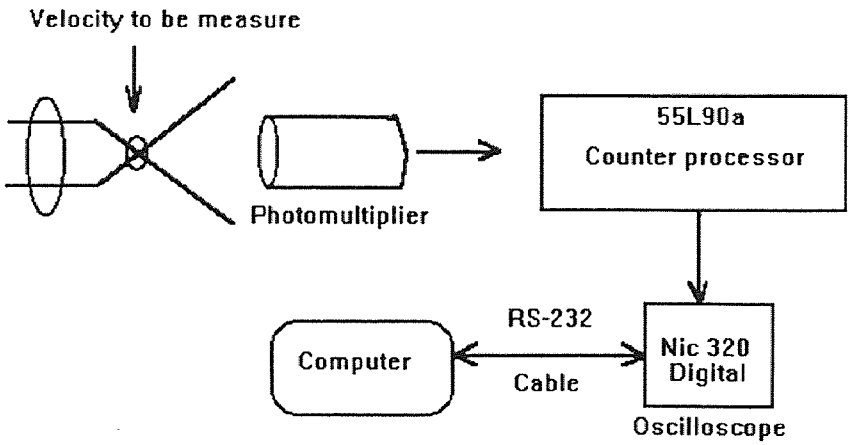


Figure 7.1 Block Diagram of the Velocity Measurement System

7.2 Focus Point Finding

Two concentrated laser beams were focused on the low pressure jet, a 10X magnifying glass put behind the jet in order to observe the laser light and the jet. Use the hand wheel on the control panel to align the jet at the center with the two parallel laser beams. The X axis focusing distance is 600 mm. It can get by using ruler rugged. For Y axis, when two laser beams hit low pressure waterjet, it projected two horizontal lights on the background. To find the focusing point by examined the projecting light that is same bright and same length to each other, then by using hand wheel on the control panel on X axis to attain accurate focusing distance on X direction.

7.3 Cutting System Programming

On two and a half axis wterjet work cell, the controller limits 300 sec turn on without robot movement. In order increase the time limit to 600-900 sec by adding same line of time control of CNC program.

After aligned the focusing point, press the "shift" and "stop" button together to turn off waterjet when changes stand off distance, in order to avoid lost focusing. Because press "emergency stop" button created vibration.

CHAPTER 8

EXPERIMENTAL RESULTS AND DISCUSSION

The waterjet formed by the highly pressurized water then passing through the sapphire nozzle is called pure waterjet for distinction in this study. The new techniques was developed, in order to measure the center velocities of pure waterjet manual and automatically by using laser transit anemometer (LTA). The sapphire nozzles #10 was used in the presented study, and the discharge pressure was maintained at 50,000 Psi. Appendix B show the distribution of velocity obtained at the difference stand-off distances, there are 0.5mm, 2mm, 6mm, 18mm, 54mm, 108mm and 155mm. The results shown in these figures indicate the relative frequency (the number of occurrence) of the velocities.

In this work, the time between two peaks are download from oscilloscope. The velocities are distance between two focusing point divided by time which calculated above. When two peaks are above 150 mv and all other peaks are below +/- 50 mv, then we considered that oscilloscope is receiving a satisfactory signal. By using this method, the "noise" associated with the measurement can be discarded. The mean velocity of each measurement is estimated by taking the arithmetic mean. Comparing the frequency distribution of velocity obtained at different stand-off distances. The scattering of jet velocities increases along the down stream of the jet. It due to the jet coherence decreases. The mean velocities from measurement are 787.37 m/s, 776.03 m/s, 723.96 m/s, 650.23 m/s, 568.84 m/s, 547.88 m/s, 482.18 m/s. It shown in Figure 8.1.

The automatic LTA measurement was developed and successfully obtain the velocities of same stand-off distance as manual LTA measurement. It was 780 m/s, 770 m/s, 720 m/s, 650 m/s, 580 m/s, 520 m/s and 440 m/s, shown in Figure 8.2. Here also

observed that the center velocities of pure waterjet tend to decrease along the axial direction. It indicates that the waterjet energy dispersed during the transverse direction.

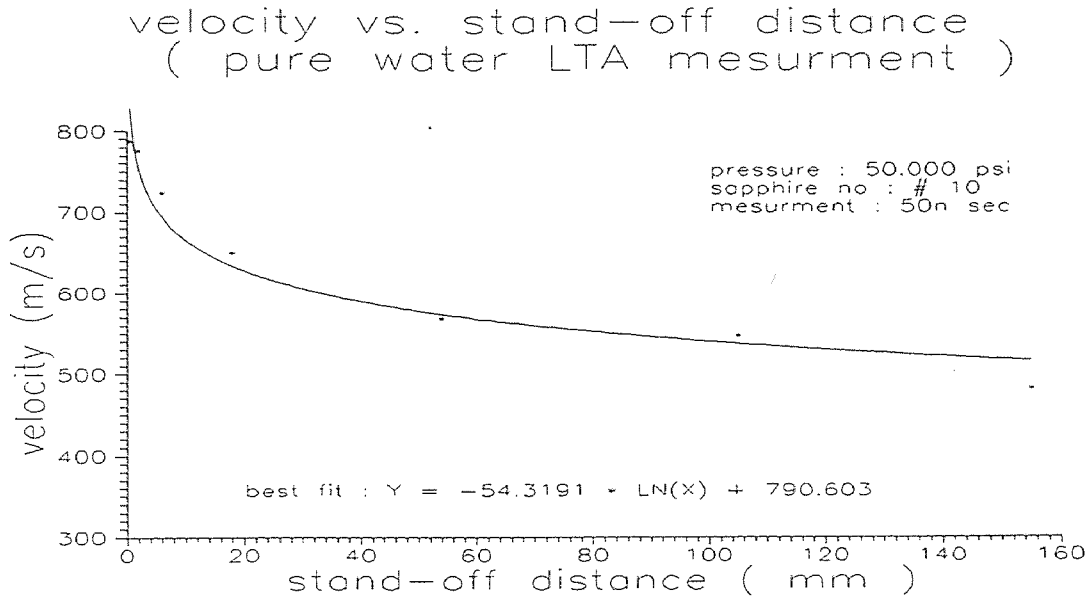


Figure 8.1 Manual LTA Velocity Measurement

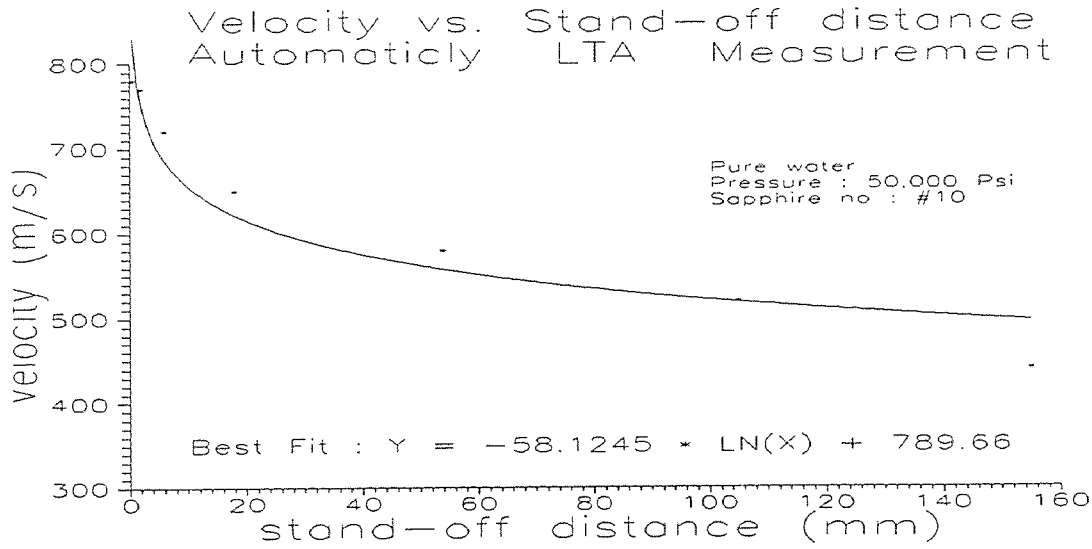


Figure 8.2 Automaticly LTA Velocity Measurement

CHAPTER 9

CONCLUSION

Because of computer speed, memory, and computational capabilities, the final link in a chain from laser transit anemometer though counter processor and oscilloscope to computer are established. Efficient transfers and define LTA measurement signal directly to computer, after calculated, output the file of velocities reading. It helped LTA velocity measurement time by 80% and eliminates the errors caused by man make.

A new system was developed by used LTA to measure the velocities of the particles entrained in the waterjet automatically. Those values were compared with the one obtained by the manual way. (Figure 9.1)

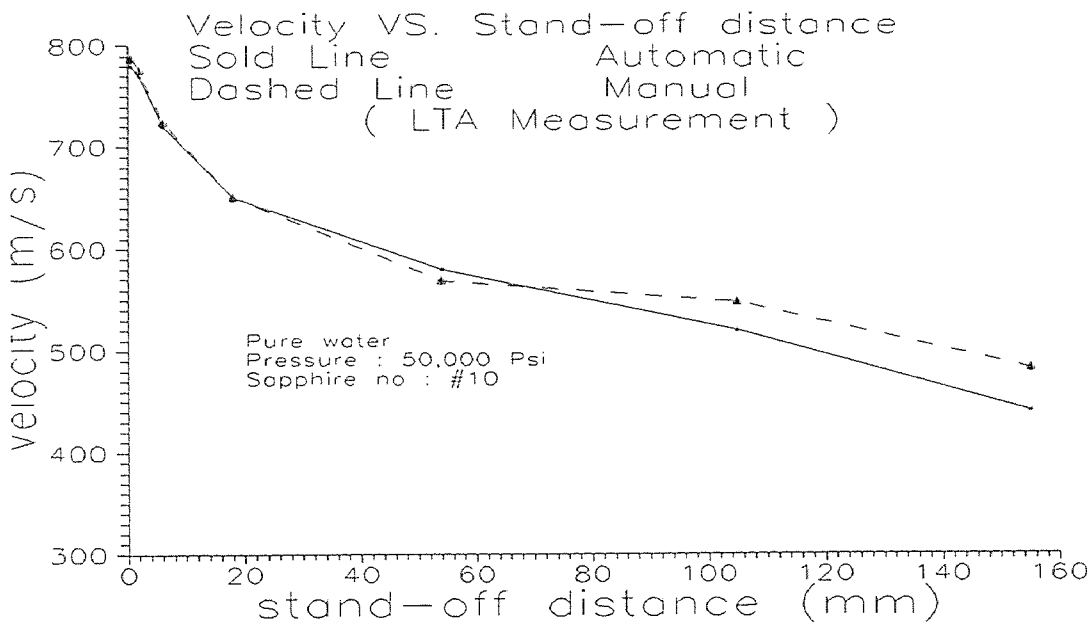


Figure 9.1 LTA Velocity Measurement (Automatic VS. Manual)

The question of automatic measurements of LTA for the waterjet is validated and the conclusions of this study can be listed as follows :

1. LTA can be used for the velocity's measurement of the waterjet automatically, which used the setup described in this work. The technique was developed and validated.
2. Increase the efficiency of waterjet velocity measurement along the down stream by 80%.
3. The result of automatic velocity measurement was shown in Fig. 8-2, the velocity reading from 780 m/s, 770 m/s, 720 m/s, 650 m/s, 580 m/s, 520 m/s to 440 m/s on the stand-off distance from 0.5 mm, 2 mm, 6 mm,. 18 mm. 54 mm, 105 mm, to 155 mm.
4. Compared the automatic and manual measurement was shown in Fig 9-1. The sold line is more smooth than dashed lines because of the sample rate are higher and result should be more reliable and accuracy.

APPENDIX A

LASER TRANSIT ANEMOMETRY (LTA) SIGNAL SIMULATION

There are two independent electronic system in LTA, each taking one focus as its detector for the first pulses. one of there two system always secures the incorrect stop pulse, while the other can receive correct and incorrect stop pulses. The relation between the counts and the probability of a particle traveling directly from the first focal point to the second is analyzed statistically for these two systems.

There are five possible cases regarding the travel of particles as shown in Figure A.1

1) A particle travels directly from the first focus A to the second focus B within T. The probability of this event is P_s.

2) After a particle passes through focus A, no other particle crosses focus B during time T the probability of this event is denoted by P_{ao}.

3) After a particle passes focus A, another particle crosses focus B during time T. The probability of this event is denoted by P_{ab}.

4) After a particle passes focus B, no other particle crosses focus A during time T.
This probability is P_{bo}.

5) After a particle passes focus B, another particle crosses the focus A during T. The probability of this event is P_{ba}.

For homogeneous turbulence, if the distance between the two foci is small enough, the turbulence parameter can be considered constant. Then event 3 and 5, start and stop are independent which gives,

Then $P_{ab} = P_{ba}$ ---------- 1.1

For system1, event 1 or event 3 can both increase the counts of n1.

Hence $P_+ = P_s + P_{ab}$ ---------- 1.2

For system 2, only event 5 can increase the counts of n2

Hence $P_- = P_{ba}$ ---------- 1.3

From the above equations,

$$P_S = P_+ - P_- \text{ ---------- } 1.4$$

P_S / P_+ is the percentage of correct stop signals in the measurements by system 1. by using eq.1.4, we can measure the probability of a particle traveling directly from the first focal point to the second by making use of the counts. If the particle distribution is randow, the time average will be homogeneous for steady flow within the measuring time.

The average of T_2 should be equal to the half width 0.5 T. T'_1 is the arithematic average of T_1. The true average value of particle flight time between the two foci t can be determined from,

$$T'_1 = t\,P_S / P + T\,(P_+ - P_S) / 2P_+ \text{ ---------- } 1.5$$

For a stable flow we can carefully adjust the width to reach this point.

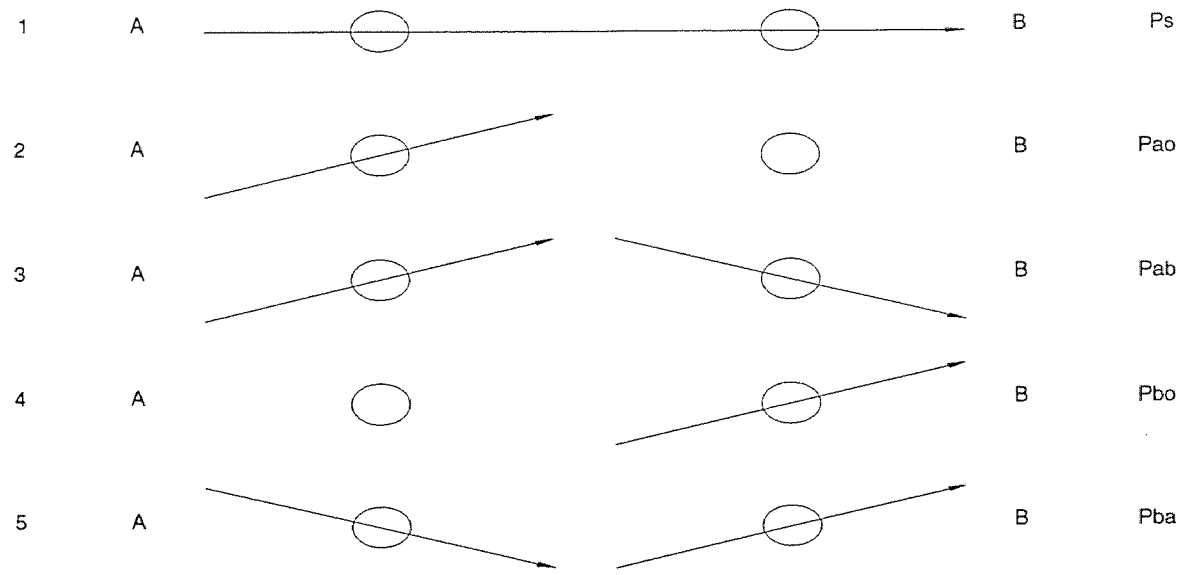


Figure A.1 The five possible cases relating to the travel of particles

APPENDIX B

FIOWCHART FOR PROGRAM PROCESSING

The functions of each sub program are listed below.

Subconfigmenu:	According to difference PC or dates transfer speed. The baud rate, parity bite, PC port will be defined.
Subsetup:	Initial value input.
Subtestrange:	Logically defining the two peaks of signal and find the range.
Subtest:	It operated both in initial data value and the data from subtestrange. Calculate between two peaks, and convert to velocity output file.
Subdownload:	It transfers dates in two ways, one is each time 4k the other way is dates from subfindrange each time data contain much less than 4K.
Subgetint:	Get the setup file or input dates that in program as initial value.
Subgetread:	Set horizontal and vertical range.

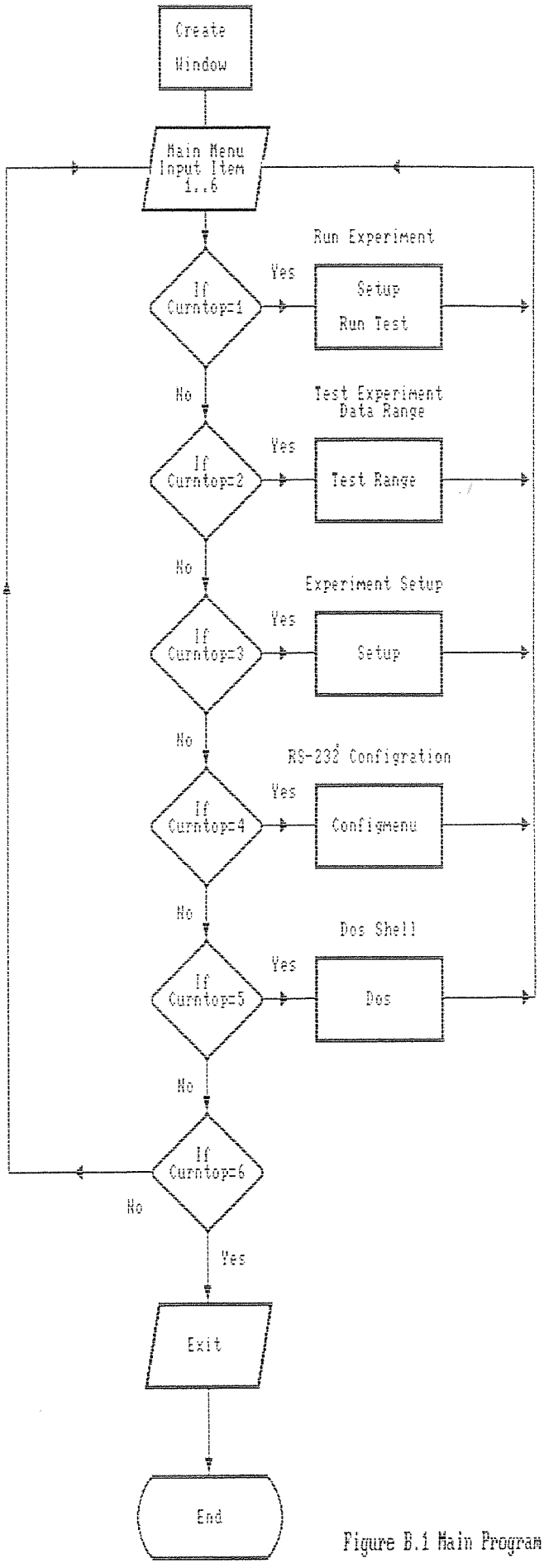


Figure B.1 Main Program

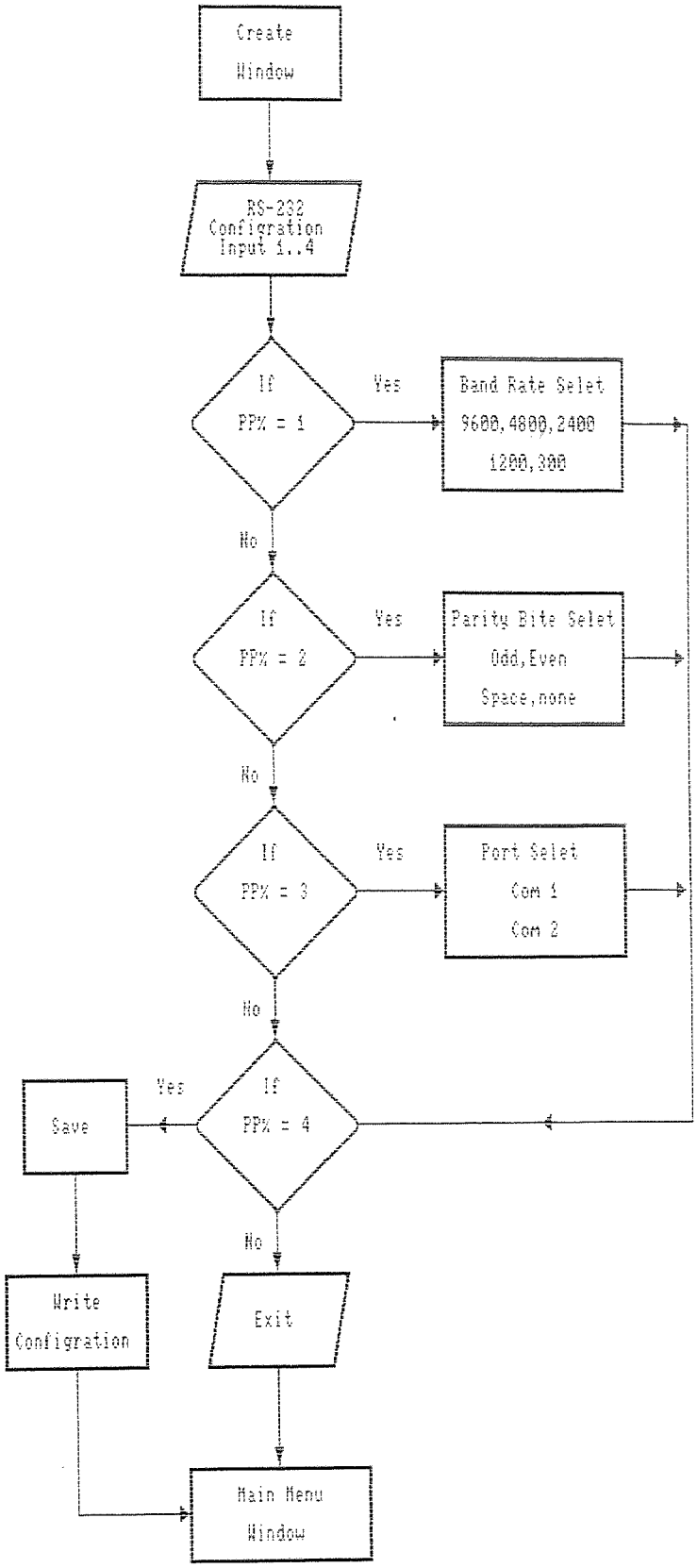


Figure B.2 Sub Program Configmenu

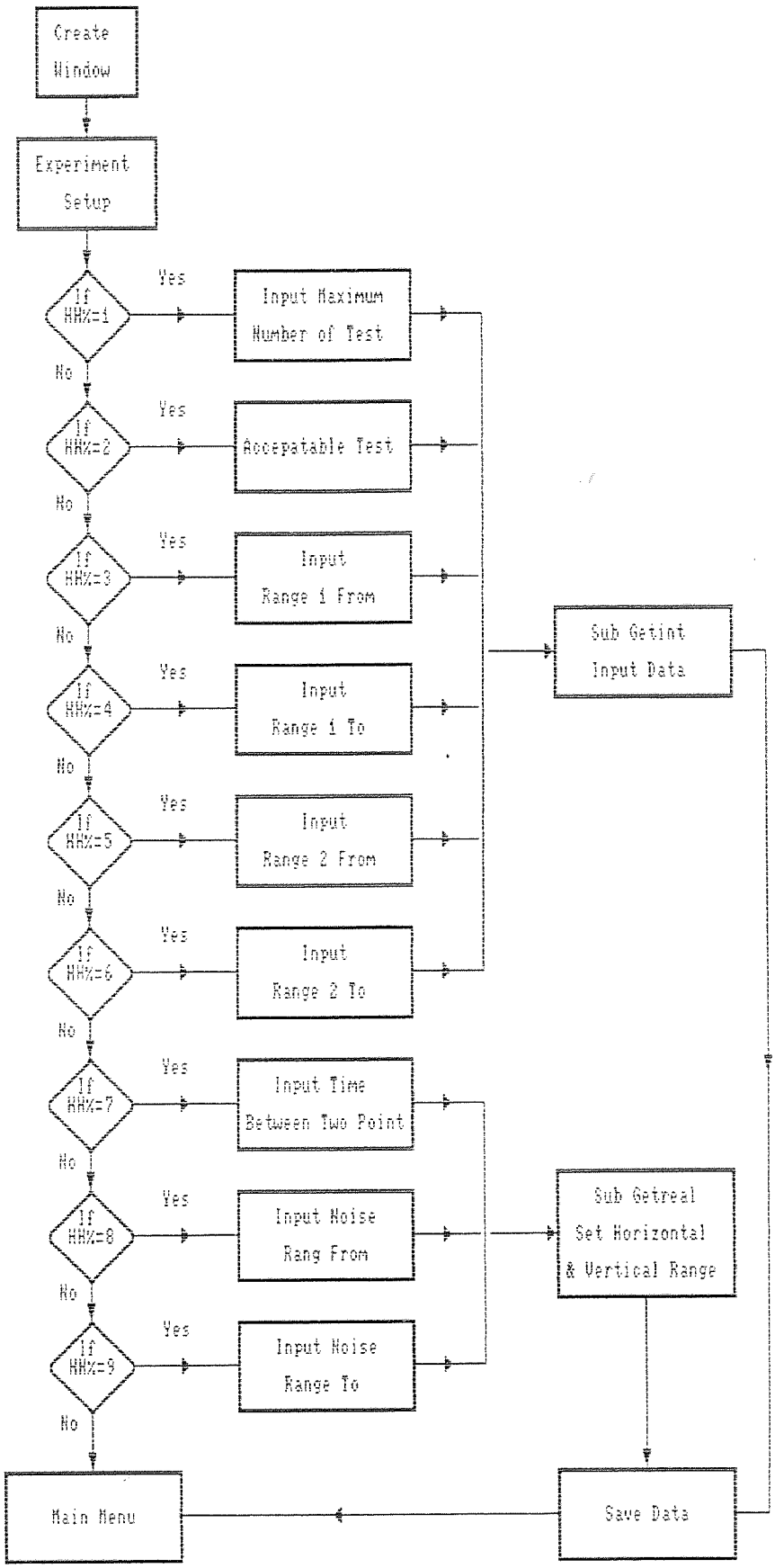


Figure B.3 Sub Program Setup

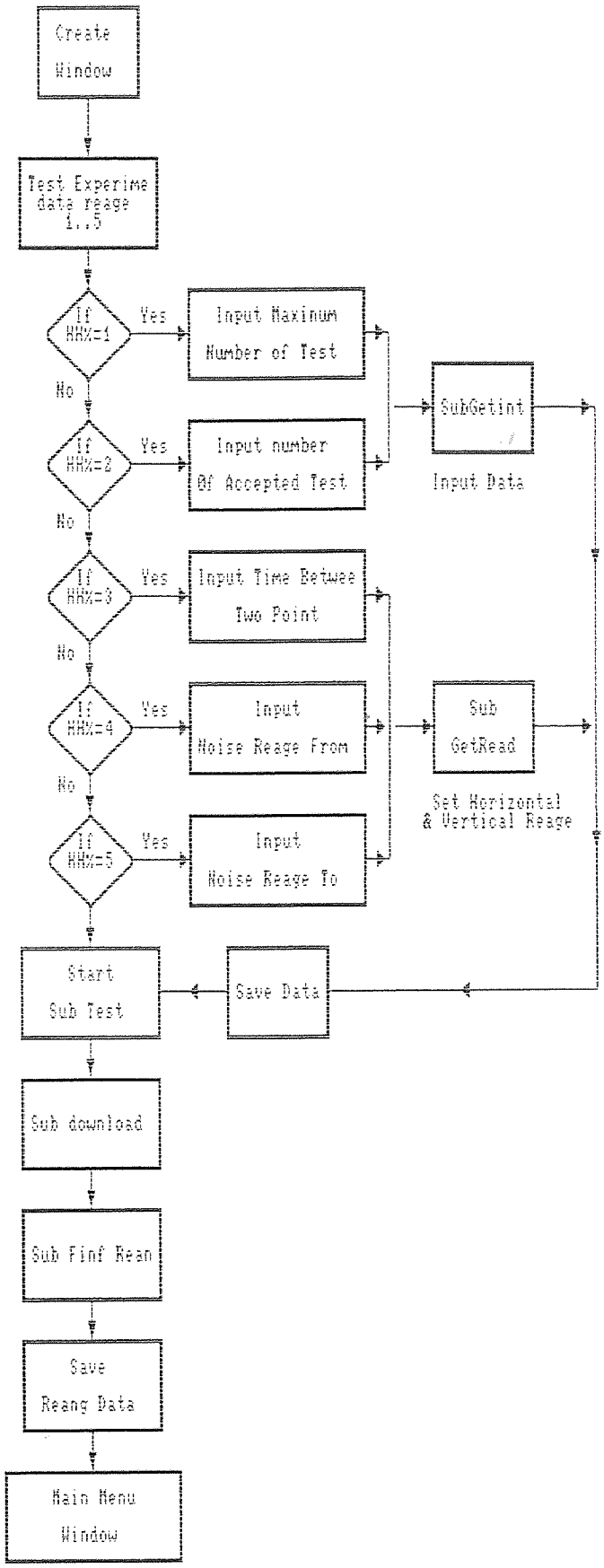


Figure B.4 Sub Program Test Range

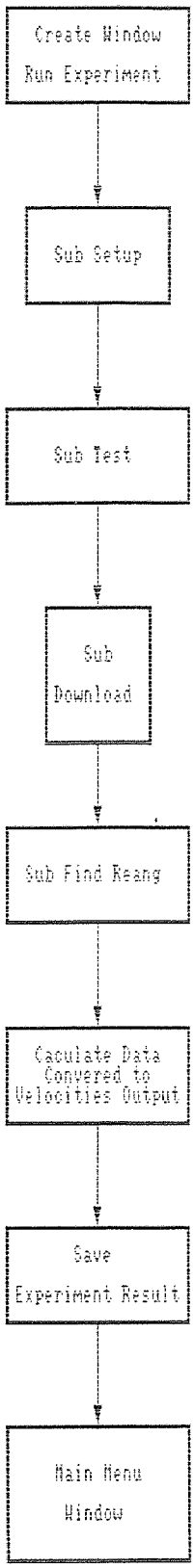


Figure B.5 Sub Program Run Test

APPENDIX C

TURBO BASIC PROGRAM FOR AUTOMATIC SIGNAL IDENTIFICATION

```
$INCLUDE "TBWINDO.INC"
$INCLUDE "TBMENU.INC"

cls
DIM T#(4000),V#(4000),IPARA$(1:20),RPARA$(1:20)
DIM TSPEED#(4000),TX1%(4000),TX2%(4000)
CALL READCONFIG
item$(1) = "Run Experiment"
item$(2) = "Test Experiment Data Range"
item$(3) = "Experiment Setup"
item$(4) = "RS-232 Configuration"
item$(5) = "DOS Shell"
item$(6) = "EXIT"
itemcount% = 6
mtitle$ = "[ Main Menu ]"
mrow% = 6
mcol% =20
mwidth%=40
mattr% = fnattr%(7,1)
mhiattr% = fnattr%(0,7)
mbrdrsel%=2
mshadow%=0
mzoom%=0
startpos%=1


while (E$<>"EXIT")
out &H03d9,7
call qfill(1,1,25,80,177,fnattr%(0,7))
CALL MAKEMENU
select case curntpos%
```

```
  case 1
    CALL SETUP
    CALL RUNTEST
  case 2
    CALL TESTRANGE
  case 3
    CALL SETUP
  case 4
    CALL CONFIGMENU
  case 5
    cls
    shell
  case 6
    E$="EXIT"
    CLS
END SELECT
WEND


NEXT I
TMX1#=0 : TMX2#=0
FOR I=1 TO K%
TMX1#=TMX1#+TSPEED#(I)

NEXT I
TMX1#=TMX1#/K%
FOR I=1 TO K%
TMX2#=TMX2#+(TMX1#-TSPEED#(I))^2

NEXT I
TMX2#=SQR(TMX2#/(K%-1))
PRINT #3,
PRINT #3,TMX1#;CHR$(241);TMX2#;" m/sec"

close #3
```

```
LOCATE 11,22 : PRINT "<< EXPERIMENT END PRESS ESC TO QUIT >>"
x$=""
WHILE x$<>chr$(27)
x$=inkey$
wend

CALL REMOVEWINDOW
COLOR 7,0
END SUB


SUB INI320
SHARED BAUD$,PARITY$,COMX$,WAVE$
local PORT$,U%
IF PARITY$="NONE" THEN D$=",8,1" ELSE D$=",7,1"
PORT$=COMX$+":"+BAUD$+","+LEFT$(PARITY$,1)+D$+",CS,DS,CD"
OPEN PORT$ AS #1
PRINT #1,"RS,CR"
PRINT #1,"STATUS"
INPUT #1,U% : INPUT #1,U%

IF ( (U% AND 16) <> 0) THEN
 WAVE$="A"
ELSEIF ( (U% AND 32) <> 0) THEN
 WAVE$="B"
ELSE
 WAVE$="A"
END IF

PRINT #1,"RS,CR"
PRINT #1,"SRQON"
PRINT #1,"CCON"
PRINT #1,"HN"
DELAY 1.0
PRINT #1,"CCOFF"
CLOSE #1
```

```
END SUB

SUB SETUP
COLOR 7,1
SHARED QUITEM$,IPARA$(),RPARA$()
local x$
CALL MAKEWINDOW(5,10,12,60,FNATTR%(7,1),2,0,0)
CALL TITLEWINDOW(2,"[ Experiment Setup ]")
LOCATE 7,12  : PRINT "MAXIMUM NUMBER OF TEST  := "
LOCATE 8,12  : PRINT "ACEPATABLE TEST         := "
LOCATE 10,12 : PRINT "RANGE 1 FROM POINT       TO POINT        "
LOCATE 11,12 : PRINT "RANGE 2 FROM POINT       TO POINT        "
LOCATE 13,12 : PRINT "TIME BETWEEN TWO POINT  :=       (usec)"
LOCATE 14,12 : PRINT "NOISE RANGE FROM        :=       (mV) TO       (mV) "
LOCATE 10,32 : PRINT IPARA$(3) : LOCATE 10,48 : PRINT IPARA$(4)
LOCATE 11,32 : PRINT IPARA$(5) : LOCATE 11,48 : PRINT IPARA$(6)
LOCATE 7,39  : PRINT IPARA$(7) : LOCATE 8,39  : PRINT IPARA$(8)
LOCATE 14,39 : PRINT RPARA$(1) : LOCATE 14,54 : PRINT RPARA$(2)
LOCATE 13,39 : PRINT RPARA$(3)

HH%=1 : QUITEM$=""
while (QUITEM$<>chr$(27))
select case HH%
 case = 1
 call GetInt(7,39,4,7)
 case = 2
 call GetInt(8,39,4,8)
 case = 3
 call GetInt(10,32,4,3)
 case = 4
 call GetInt(10,48,4,4)
 case = 5
 call GetInt(11,32,4,5)
 case = 6
 call GetInt(11,48,4,6)
```

```
 case = 7
 call GetReal(13,39,7,"P",3)
 case = 8
 call GetReal(14,39,7,"",1)
 case = 9
 call GetReal(14,54,7,"",2)
end select

IF (mid$(QUITEM$,2,1)="H") THEN
  IF HH% = 1 THEN HH% = 9 ELSE HH% = HH% - 1
ELSEIF ( (mid$(QUITEM$,2,1)="P") or  (QUITEM$=chr$(13)) ) THEN
  IF HH% = 9 THEN HH% = 1 ELSE HH% = HH% + 1
END IF

wend
CALL REMOVEWINDOWEND

SUB RUNTEST
COLOR 7,1
SHARED QUITEM$,IPARA$(),RPARA$(),T#(),V#(),TSPEED#()
local x$,P1R1%,P1R2%,P2R1%,P2R2%,ED%,AC%,TMX1#,TMX2#,PV#,TI#,N1#,N2#
CALL MAKEWINDOW(10,10,7,60,FNATTR%(7,1),2,0,0)
CALL TITLEWINDOW(2,"[ RUN EXPERIMENT ]")
LOCATE 11,22 : PRINT "<< PRESS ESC KEY TO STOP EXPERIMENT >>"
ED%=VAL(IPARA$(7))   :AC%=VAL(IPARA$(8))
P1R1%=VAL(IPARA$(3)) :P1R2%=VAL(IPARA$(4))
P2R1%=VAL(IPARA$(5)) :P2R2%=VAL(IPARA$(6))
TI#=VAL(RPARA$(3))/1000000.0
N1#=VAL(RPARA$(1))/1000.0 : N2#=VAL(RPARA$(2))/1000.0
IF N1#<N2# THEN SWAP N1#,N2#

K%=0

CALL INI320
OPEN "RUNTEST.DAT" FOR OUTPUT AS #3
```

```
FOR I=1 TO ED%
CALL DOWNLOAD(P1R1%,P2R2%,"Y")
'CALL DOWNLOAD(P2R1%,P2R2%,"N")
'stop
LOCATE 13,15 : PRINT "NUMBER HAVE TESTED := ";I
FOR J=P1R1% TO P1R2%
IF V#(J)<=N1# THEN V#(J)=N1#
NEXT J
FOR J=P2R1% TO P2R2%
IF V#(J)<=N1# THEN V#(J)=N1#
NEXT J

TMX1#=0 : PV#=0
FOR J=P1R1% TO P1R2%
IF ( V#(J-1)<=V#(J) AND V#(J)>=V#(J+1) AND V#(J)<>N1# ) THEN
 IF V#(J)>PV# THEN PV#=V#(J) : TMX1#=T#(J)
END IF
NEXT J

TMX2#=0 : PV#=0
FOR J=P2R1% TO P2R2%
IF ( V#(J-1)<=V#(J) AND V#(J)>=V#(J+1) AND V#(J)<>N1# ) THEN
 IF V#(J)>PV# THEN PV#=V#(J) : TMX2#=T#(J)
END IF
NEXT J

IF (TMX1#<>0 AND TMX2#<>0 AND (TMX2#-TMX1#)<=TI#) THEN
 K%=K%+1
 TSPEED#(K%)=(449.0E-6)/(TMX2#-TMX1#)
 LOCATE 14,15 : PRINT "ACEPTABLE TESTED  := ";K%
 PRINT #3,K%,TSPEED#(K%)
 IF K%=AC% THEN I=ED%
END IF
```

```
x$=INKEY$
IF x$=CHR$(27) THEN I=ED%

END SUB

SUB TESTRANGE
SHARED QUITEM$,IPARA$(),RPARA$()
LOCAL HH%,TermChar$,MAX%,ACC%,x$
CALL MAKEWINDOW(10,10,12,60,FNATTR%(7,1),2,0,0)
CALL TITLEWINDOW(2,"[ TEST EXPERIMENT DATA RANGE ]")
COLOR 7,1

LOCATE 11,12 : PRINT "MAXIMUM NUMBER OF TEST  :="
LOCATE 12,12 : PRINT "NUMBER OF ACCEPTED TEST :="
LOCATE 13,12 : PRINT "TIME BETWEEN TWO POINT  :=       (usec)"
LOCATE 14,12 : PRINT "NOISE RANGE FROM        :=       (mV) TO       (mV) "
LOCATE 16,24 : PRINT "<< PRESS F1 KEY TO START TEST >>"

LOCATE 11,39 : PRINT IPARA$(1) : LOCATE 12,39 : PRINT IPARA$(2)
LOCATE 14,39 : PRINT RPARA$(1) : LOCATE 14,54 : PRINT RPARA$(2)
LOCATE 13,39 : PRINT RPARA$(3)

HH%=1 : QUITEM$=""
while (QUITEM$<>chr$(27))
select case HH%
 case = 1
 call GetInt(11,39,4,1)
 case = 2
 call GetInt(12,39,4,2)
 case = 3
 call GetReal(13,39,7,"P",3)
 case = 4
 call GetReal(14,39,7,"",1)
 case = 5
 call GetReal(14,54,7,"",2)
end select
```

```
IF (mid$(QUITEM$,2,1)="H") THEN
  IF HH% = 1 THEN HH% = 5 ELSE HH% = HH% - 1
ELSEIF ( (mid$(QUITEM$,2,1)="P") or  (QUITEM$=chr$(13)) ) THEN
  IF HH% = 5 THEN HH% = 1 ELSE HH% = HH% + 1
END IF

IF (mid$(QUITEM$,2,1)=";") THEN call TEST

wend

COLOR 7,0
CALL REMOVEWINDOW
END SUB


SUB TEST
SHARED QUITEM$,NACEP%,IPARA$(),TSPEED#(),TX1%(),TX2%()
LOCAL
x$,N1%,N2%,N3#,N4#,N5#,TSP#,R11%,R12%,R21%,R22%,R1#,R2#,B1#,B2#,A#
LOCATE 16,17 : PRINT "<< TESTING, TO TERMINATE TEST PRESS ESC KEY
>>"
LOCATE 17,17 : PRINT SPACE$(50)
LOCATE 18,17 : PRINT SPACE$(50)
LOCATE 19,17 : PRINT SPACE$(50)
LOCATE 20,17 : PRINT SPACE$(50)

N1%=VAL(IPARA$(1)) : N2%=VAL(IPARA$(2))

NACEP%=0

CALL INI320

FOR I=1 TO N1%
LOCATE 18,17 : PRINT "TIMES OF TEST HAVE RUN :=";I
x$=inkey$ : if (x$=chr$(27)) then I=N1%
```

```
CALL DOWNLOAD(1,4000,"Y")
x$=inkey$ : if (x$=chr$(27)) then I=N1%
CALL FINDRANGE
x$=inkey$ : if (x$=chr$(27)) then I=N1%
if (NACEP%=N2%) then I=N1%
LOCATE 19,17 : PRINT "ACCEPTABLE TEST        :=";NACEP%
NEXT I

TSP#=0.0 : R1#=0 : R2#=0
R11%=0 : R12%=0 : R21%=0 : R22%=0

FOR I=1 TO NACEP%
TSP#=TSP#+TSPEED#(I)
R1#=R1#+TX1%(I)
R2#=R2#+TX2%(I)
NEXT I

TSP#=(TSP#/NACEP%) : R1#=(R1#/NACEP%) : R2#=(R2#/NACEP%)
A#=0 : B1#=0 : B2#=0

FOR I=1 TO NACEP%
A#=A#+(TSP#-TSPEED#(I))^2
B1#=B1#+(R1#-TX1%(I))^2
B2#=B2#+(R2#-TX2%(I))^2
NEXT I

R11%=FIX(R1#-3*SQR(B1#/(NACEP%-1))) :
R12%=FIX(R1#+3*SQR(B1#/(NACEP%-1)))+1
R21%=FIX(R2#-3*SQR(B2#/(NACEP%-1))) :
R22%=FIX(R2#+3*SQR(B2#/(NACEP%-1)))+1
B1#=3*SQR(A#/(NACEP%-1))

LOCATE 16,17 : PRINT "      << PRESS F1 KEY TO START TEST >>      "
LOCATE 17,17 : PRINT SPACE$(50)
LOCATE 18,17 : PRINT SPACE$(50)
LOCATE 19,17 : PRINT SPACE$(50)
```

```
LOCATE 20,17 : PRINT SPACE$(50)
LOCATE 18,17 : PRINT "AVERAGE SPEED := "; : PRINT USING "#####.###";TSP#;
PRINT " (m/sec)"
LOCATE 19,17 : PRINT "RANGE 1 := "; : PRINT USING "####";R11%;
PRINT " TO "; : PRINT USING "####";R12%
LOCATE 20,17 : PRINT "RANGE 2 := "; : PRINT USING "####";R21%;
PRINT " TO "; : PRINT USING "####";R22%

IPARA$(3)=RIGHT$( STR$(R11%),LEN(STR$(R11%))-1 )
IPARA$(4)=RIGHT$( STR$(R12%),LEN(STR$(R12%))-1 )
IPARA$(5)=RIGHT$( STR$(R21%),LEN(STR$(R21%))-1 )
IPARA$(6)=RIGHT$( STR$(R22%),LEN(STR$(R22%))-1 )

QUITEM$=""

OPEN "TRANGE.DAT" FOR OUTPUT AS #1
FOR I=1 TO NACEP%
PRINT #1,I,TSPEED#(I);" m/sec"
NEXT I
PRINT #1,
PRINT #1,"SPEED := ";TSP#;CHR$(241);B1#;" m/sec"
PRINT #1,
PRINT #1,"RANGE 1 := "; : PRINT #1,USING "####";R11%;
PRINT #1," TO "; : PRINT #1,USING "####";R12%
PRINT #1,"RANGE 2 := "; : PRINT #1,USING "####";R21%;
PRINT #1," TO "; : PRINT #1,USING "####";R22%
CLOSE #1

END SUB



SUB FINDRANGE
SHARED NACEP%,RPARA$(),T#(),V#(),TSPEED#(),TX1%(),TX2%()
LOCAL x$,N1#,N2#,N3#,J%,K%,SEC%(),VMAX#(),TMAX#(),IX%(),TEM#
DIM SEC%(500,1:2),TMAX#(500),VMAX#(500),IX%(500)
```

```
N1#=VAL(RPARA$(1))/1000.0 : N2#=VAL(RPARA$(2))/1000.0
N3#=VAL(RPARA$(3))/1000000.0
K%=0
IF N2#>N1# THEN SWAP N1#,N2#

FOR I=1 TO 4000
 IF V#(I)<=N1# THEN V#(I)=N1#
' locate 20,1 : print I
NEXT I

FOR I=1 TO 4000

 IF V#(I)>N1# THEN

 K%=K%+1
 SEC%(K%,1)=I
 while ( V#(I)>N1# )
 I=I+1
 wend
 SEC%(K%,2)=(I-1)
 END IF

'locate 20,50 : print I,K%
NEXT I

IF K%<>0 THEN

FOR J=1 TO K%
 VMAX#(J)=N1#
 FOR L=SEC%(J,1) TO SEC%(J,2)
 IF V#(L)>VMAX#(J) THEN VMAX#(J)=V#(L) : TMAX#(J)=T#(L) : IX%(J)=L
' locate 21,50 : print L
 NEXT L
NEXT J
```

```
TEM#=0
FOR I=1 TO K%
IF VMAX#(I)>TEM# THEN TEM#=VMAX#(I) : ST%=I
NEXT I

FOR I=ST% TO K%
 FOR H=ST% TO K%
 IF VMAX#(H) < VMAX#(I) THEN
 SWAP VMAX#(H),VMAX#(I)
 SWAP TMAX#(H),TMAX#(I)
 SWAP IX%(H),IX%(I)
 END IF
' locate 22,50 : print "swap"
 NEXT H
NEXT I

IF ((TMAX#(ST%+1)-TMAX#(ST%))<=N3#  AND VMAX#(ST%)<>N1# AND
VMAX#(ST%+1)<>N1#) THEN
  NACEP%=NACEP%+1
  TSPEED#(NACEP%)=(449.0E-6)/(TMAX#(ST%+1)-TMAX#(ST%))
  TX1%(NACEP%)=IX%(ST%)
  TX2%(NACEP%)=IX%(ST%+1)
END IF

END IF
'locate 22,55 : print "end find"
END SUB




SUB DOWNLOAD(R1%,R2%,HN$)
SHARED BAUD$,PARITY$,COMX$,WAVE$,T#(),V#()
LOCAL PORT$,D$,L$,R1$,R2$,x$,K%,DK%,R%,H%,M#(),D%()
DIM M#(5),D%(4000)
```

```
R1$=RIGHT$(STR$(R1%-1),(LEN(STR$(R1%-1))-1))
R2$=RIGHT$(STR$(R2%-R1%+1),(LEN(STR$(R2%-R1%+1))-1))
IF PARITY$="NONE" THEN D$=",8,1" ELSE D$=",7,1"
PORT$=COMX$+":"+BAUD$+","+LEFT$(PARITY$,1)+D$+",CS,DS,CD"

IF (PARITY$="NONE") THEN

OPEN PORT$ AS #1
PRINT #1,"RS,CR"
PRINT #1,"SRQON"
PRINT #1,"CCON"
IF (HN$="Y") THEN PRINT #1,"HN"
'IF (HN$="N") THEN PRINT #1,"HL"
DELAY 1.0
K%=R1% : DK%=R1%
PRINT #1,"DO,"+WAVE$+",BIN/LO,"+R1$+","+R2$
R%=(R2%-R1%+1) : H%=128
BACK1:
IF R%<1000 THEN H%=(1000-R%)*2+50
BACK2:
IF LOF(1)>H% THEN GOTO BACK2
PRINT #1,CHR$(19);
WHILE LOC(1)>1 : D%(K%)=CVI(INPUT$(2,1)) : K%=K%+1 : WEND
R%=R%-(K%-DK%)
DK%=K%
PRINT #1,CHR$(17);
IF R%>0 THEN GOTO BACK1

ELSE

OPEN PORT$ AS #1
PRINT #1,"RS,CR"
PRINT #1,"SRQON"
PRINT #1,"CCON"
IF (HN$="Y") THEN PRINT #1,"HN"
'IF (HN$="N") THEN PRINT #1,"HL"
```

```
DELAY 1.0
K%=R1% : DK%=R1%
PRINT #1,"DO,"+WAVE$+",ASC,"+R1$+","+R2$
R%=(R2%-R1%+1)
BACK3:
IF R%<285 THEN GOTO BACK5
BACK4:
IF LOF(1)>128 THEN GOTO BACK4
PRINT #1,CHR$(19);
BACK5:
WHILE LOC(1)>6 : D%(K%)=VAL(INPUT$(7,#1)) : K%=K%+1 : WEND
R%=R%-(K%-DK%)
DK%=K%
IF R%>0 THEN PRINT #1,CHR$(17); : GOTO BACK3
PRINT #1,CHR$(17);

END IF

PRINT #1,"GDOFF"
PRINT #1,"NO,"+WAVE$
L$=INPUT$(48,#1)
M#(0)=VAL(MID$(L$,3,6))
M#(1)=VAL(MID$(L$,10,6))
M#(2)=VAL(MID$(L$,17,7)+MID$(L$,25,2))
M#(3)=VAL(MID$(L$,28,7)+MID$(L$,36,2))
M#(4)=VAL(MID$(L$,39,7)+MID$(L$,47,2))

PRINT #1,"CCOFF"
CLOSE #1

'open "kk.dat" for output as #4
for i%=R1% to R2%
T#(i%)=((i%-1-M#(1))*M#(3))
V#(i%)=((D%(i%)-M#(0))*M#(4))
'locate 22,1 : print i%,T#(i%),V#(i%)
```

```
'print #4,i%,T#(i%),V#(i%)
next i%
'close #4

END SUB


SUB GetInt(Y%,X%,LENG%,P%)
SHARED QUITEM$,IPARA$()
LOCAL x$,A$
color 0,7
x$=""
A$=IPARA$(P%)
LOCATE Y%,X% : PRINT A$+SPACE$(LENG%-LEN(A$))

while ( (x$<>chr$(27)) and (x$<>chr$(13)) and (mid$(x$,2,1)<>";") and_
      (mid$(x$,2,1)<>"H") and (mid$(x$,2,1)<>"P") )
if ( (x$="1") or (x$="2") or (x$="3") or (x$="4") or (x$="5")_
  or (x$="6") or (x$="7") or (x$="8") or (x$="9") or (x$="0")_
  or (x$=chr$(8)) ) then

   if ( ( x$="0" or x$=chr$(8) ) and LEN(A$)=0 ) then
     BEEP
   elseif ( LEN(A$)<=(LENG%-1) and x$<>chr$(8) ) then
     A$=A$+x$
   elseif ( LEN(A$)=>1 and x$=chr$(8) ) then
     A$=LEFT$(A$,(LEN(A$)-1))
   else
   BEEP
   end if

   if (LEN(A$)<=LENG%) THEN
   locate Y%,X% : PRINT A$+SPACE$(LENG%-LEN(A$))
   end if

elseif ( (x$<>"") ) then
```

```
   BEEP
END IF
x$=inkey$
WEND
QUITEM$=x$ : color 7,1 : locate Y%,X%
PRINT A$+SPACE$(LENG%-LEN(A$))
IPARA$(P%)=A$
end sub



SUB GetReal(Y%,X%,LENG%,B$,P%)
SHARED QUITEM$,RPARA$()
LOCAL x$,A$
color 0,7
x$=""
A$=RPARA$(P%)
LOCATE Y%,X% : PRINT A$+SPACE$(LENG%-LEN(A$))


while ( (x$<>chr$(27)) and (x$<>chr$(13)) and (mid$(x$,2,1)<>";") and_
      (mid$(x$,2,1)<>"H") and (mid$(x$,2,1)<>"P") )
if ( (x$="1") or (x$="2") or (x$="3") or (x$="4") or (x$="5")_
 or (x$="6") or (x$="7") or (x$="8") or (x$="9") or (x$="0")_
 or (x$=".") or (x$="-") or (x$=chr$(8)) ) then

   if (Instr(1,A$,".")=0) then LL%=0 ELSE LL%=1
   if ( (x$=chr$(8) and LEN(A$)=0) or (B$="P" and x$="-") ) then
     BEEP
   elseif ( LEN(A$)<=(LENG%-1) and x$<>chr$(8) and NOT(LL%=1 and x$=".") and_
        NOT(LEN(A$)<>0 and x$="-") ) then
     A$=A$+x$
   elseif ( LEN(A$)=>1 and x$=chr$(8) ) then
     A$=LEFT$(A$,(LEN(A$)-1))
   else
   BEEP
```

```
   end if

   if (LEN(A$)<=LENG%) THEN
   locate Y%,X% : PRINT A$+SPACE$(LENG%-LEN(A$))
   end if

elseif ( (x$<>"") ) then
   BEEP
END IF
x$=inkey$
WEND
QUITEM$=x$ : color 7,1 : locate Y%,X%
PRINT A$+SPACE$(LENG%-LEN(A$))
RPARA$(P%)=A$
end sub

SUB CONFIGMENU
SHARED PP%
CALL MAKEWINDOW(12,20,7,40,FNATTR%(7,1),2,0,0)
CALL TITLEWINDOW(2,"[ RS-232 CONFIGURATION ]")
COLOR 7,1
LOCATE 13,30 : PRINT "BAUD RATE   :="
LOCATE 14,30 : PRINT "PARITY BITE :="
LOCATE 15,30 : PRINT "PORT        :="
LOCATE 17,30 : PRINT "EXIT / SAVE := EXIT"

CALL INITIALCFG(13,45)
PP%=1
while PP%<>0
select case PP%
  case=1
   CALL LEFTRIGHT(13,45,1,5)
  case=2
   CALL LEFTRIGHT(14,45,2,4)
  case=3
   CALL LEFTRIGHT(15,45,3,2)
```

```
  case=4
   CALL LEFTRIGHT(17,45,4,2)
end select
wend
COLOR 7,0 : CALL REMOVEWINDOW
END SUB

SUB READCONFIG
SHARED BAUD$,PARITY$,COMX$
LOCAL A$,B$,EORR%
ON ERROR GOTO FFFF
OPEN "320CFG.DAT" FOR INPUT AS #1
WHILE NOT EOF(1)
INPUT #1, A$, B$
IF A$ = "BAUD" THEN BAUD$=B$
IF A$ = "PARITY" THEN PARITY$=B$
IF A$ = "PORT" THEN COMX$=B$
WEND
CLOSE #1
EORR%=1
IF EORR%=1 THEN
 IF ( (BAUD$<>"9600") AND (BAUD$<>"4800") AND (BAUD$<>"2400") AND_
    (BAUD$<>"1200") AND (BAUD$<>"300") AND (BAUD$="") ) THEN
BAUD$="9600"
 IF ( (PARITY$<>"NONE") AND (PARITY$<>"ODD") AND (PARITY$<>"EVEN")_
    AND (PARITY$<>"SPACE") OR (PARITY$="") ) THEN PARITY$="NONE"
 IF ( (COMX$<>"COM1") AND (COMX$<>"COM2") ) THEN COMX$="COM1"
ELSE
FFFF:
BAUD$="9600"
PARITY$="NONE"
COMX$="COM1"
END IF


END SUB
```

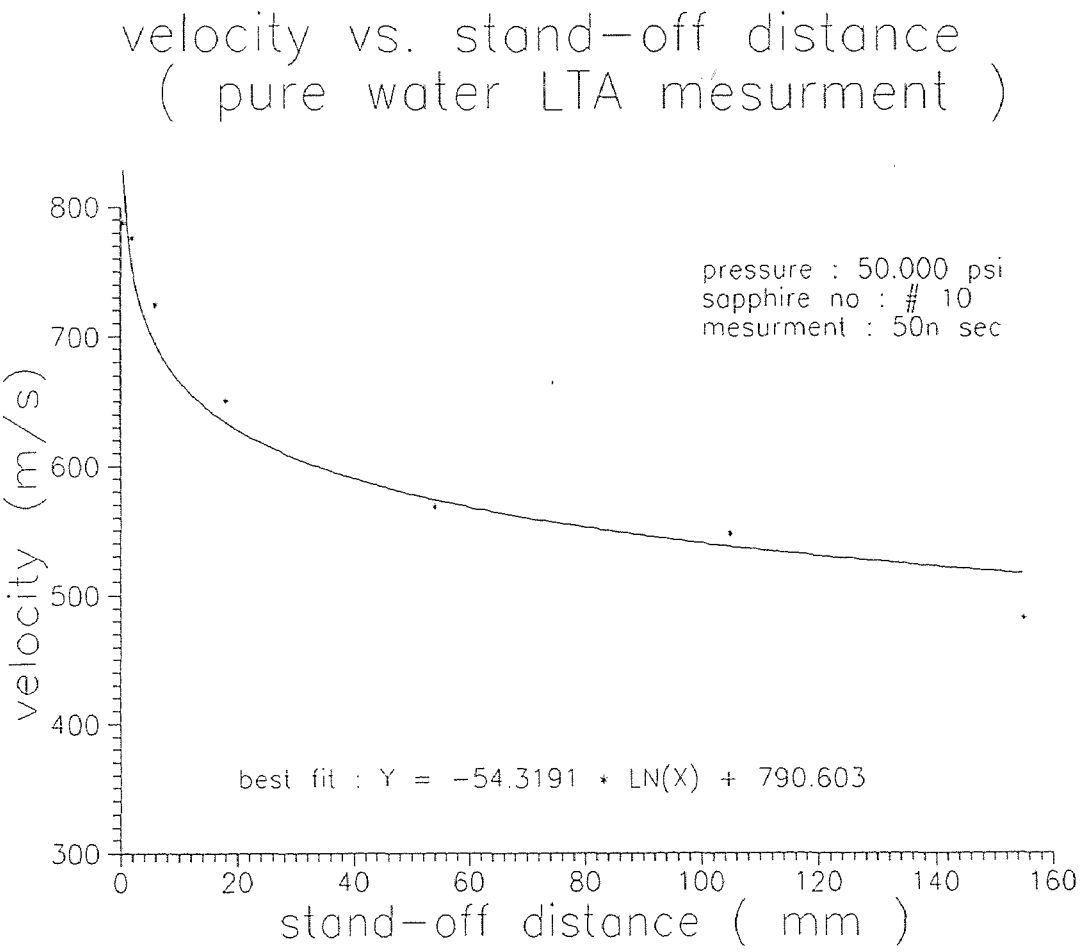
```
SUB WRITECONFIG
SHARED BAUD$,PARITY$,COMX$
OPEN "320CFG.DAT" FOR OUTPUT AS #1
PRINT #1, "INTERFACE,","RS232"
PRINT #1, "BAUD,",BAUD$
PRINT #1, "PARITY,",PARITY$
PRINT #1, "PORT,",COMX$
CLOSE #1
END SUB

SUB INITIALCFG(X%,Y%)
SHARED BAUD$,PARITY$,COMX$
LOCATE X%,Y% : PRINT BAUD$
LOCATE X%+1,Y% : PRINT PARITY$
LOCATE X%+2,Y% : PRINT COMX$
END SUB

SUB LEFTRIGHT(X%,Y%,FUNC%,ITEM%)

SHARED v$(),BAUD$,PARITY$,COMX$,PP%
dim v$(5,5)
v$(1,1)="9600" : v$(1,2)="4800" : v$(1,3)="2400" : v$(1,4)="1200" : v$(1,5)="300 "
v$(2,1)="ODD" : v$(2,2)="EVEN" : v$(2,3)="SPACE" : v$(2,4)="NONE"
v$(3,1)="COM1" : v$(3,2)="COM2"
v$(4,1)="EXIT"
v$(4,2)="SAVE"
LOCAL i%

SELECT CASE FUNC%
   CASE = 1
    FOR C%=1 TO 5
    IF ( BAUD$=v$(FUNC%,C%) ) THEN i%=C%
    NEXT C%
   CASE = 2
```

```
    FOR C%=1 TO 4
    IF ( PARITY$=v$(FUNC%,C%) ) THEN i%=C%
    NEXT C%
   CASE = 3
    FOR C%=1 TO 2
    IF ( COMX$=v$(FUNC%,C%) ) THEN i%=C%
    NEXT C%
   CASE = 4
    i%=1
END SELECT

color 0,15
locate X%,Y% : print "     "
locate X%,Y% : print v$(FUNC%,i%)
x$=""
while  ( (x$<>chr$(13)) and (mid$(x$,2,1)<>"H") and (mid$(x$,2,1)<>"P") )
x$=inkey$

if (mid$(x$,2,1)="K") then
 if i%=1 then i%=ITEM% else i%=i%-1
 locate X%,Y% : print "     "
 locate X%,Y% : print v$(FUNC%,i%)
end if

if (mid$(x$,2,1)="M") then
 if i%=ITEM% then i%=1 else i%=i%+1
 locate X%,Y% : print "     "
 locate X%,Y% : print v$(FUNC%,i%)
end if

if ( (x$=chr$(13)) or (mid$(x$,2,1)="H") or (mid$(x$,2,1)="P") ) then

  if ( (x$=chr$(13)) or (mid$(x$,2,1)="P") ) then
    if PP%=4 then PP%=1 else PP%=PP%+1
  end if
```

```
  if (mid$(x$,2,1)="H") then
    if PP%=1 then PP%=4 else PP%=PP%-1
  end if

  color 7,1
  locate X%,Y% : print "     "
  locate X%,Y% : print v$(FUNC%,i%)
  SELECT CASE FUNC%
   CASE = 1
    BAUD$=v$(FUNC%,i%)
   CASE = 2
    PARITY$=v$(FUNC%,i%)
   CASE = 3
    COMX$=v$(FUNC%,i%)
   CASE = 4
    IF ((x$=chr$(13)) and (v$(FUNC%,i%)="SAVE")) THEN CALL WRITECONFIG
:PP%=0
    IF ((x$=chr$(13)) and (v$(FUNC%,i%)="EXIT")) THEN PP%=0
  END SELECT
end if
wend
END SUB
```

APPENDIX D

MANUAL LTA VELOCITY MEASUREMENT DATES SET

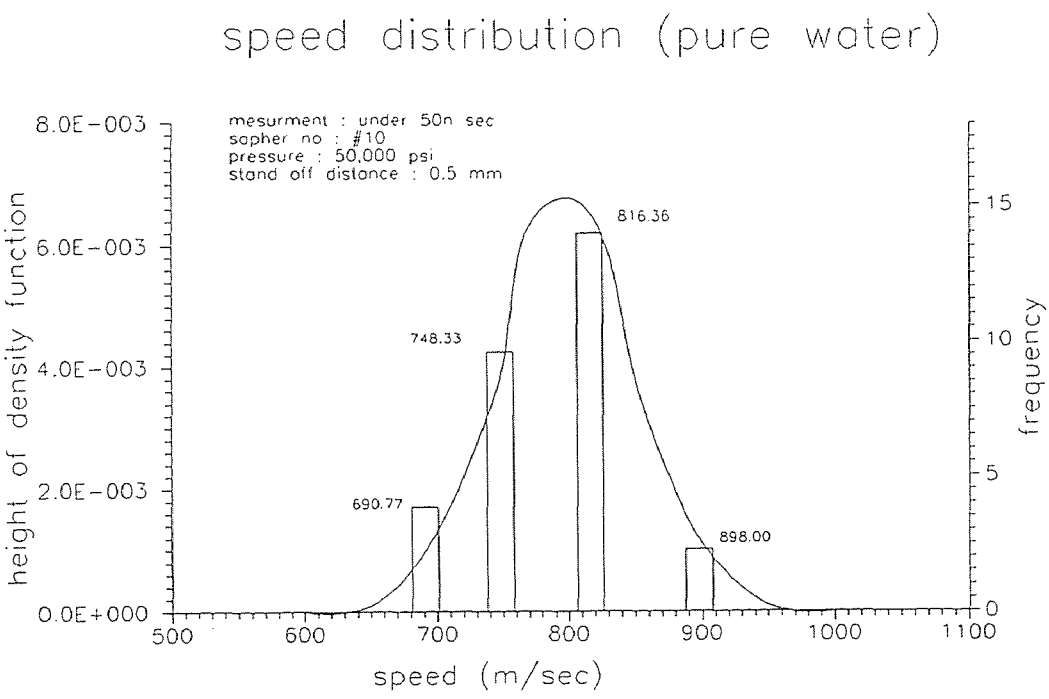


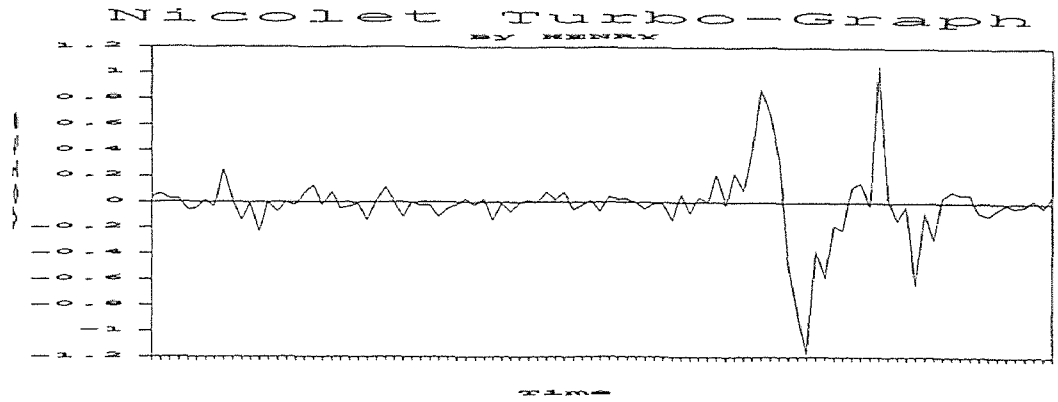
WATER JET VELOCITIES MESUREMENT

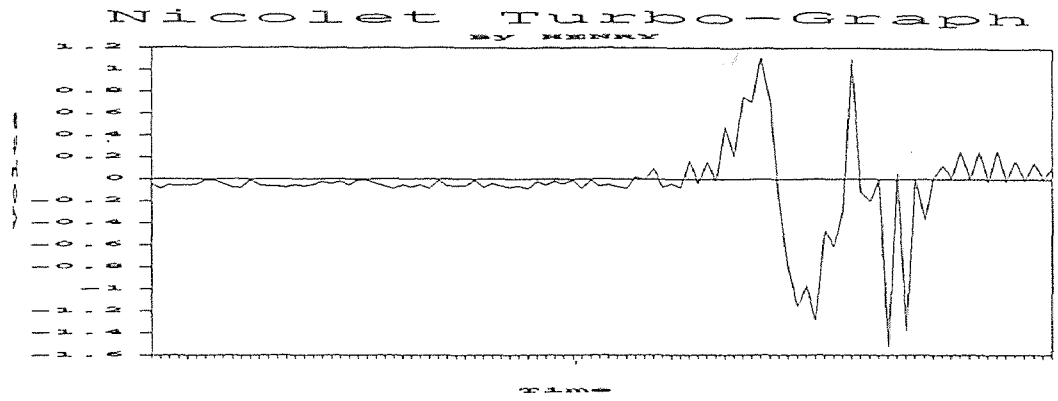
(PURE WATER)

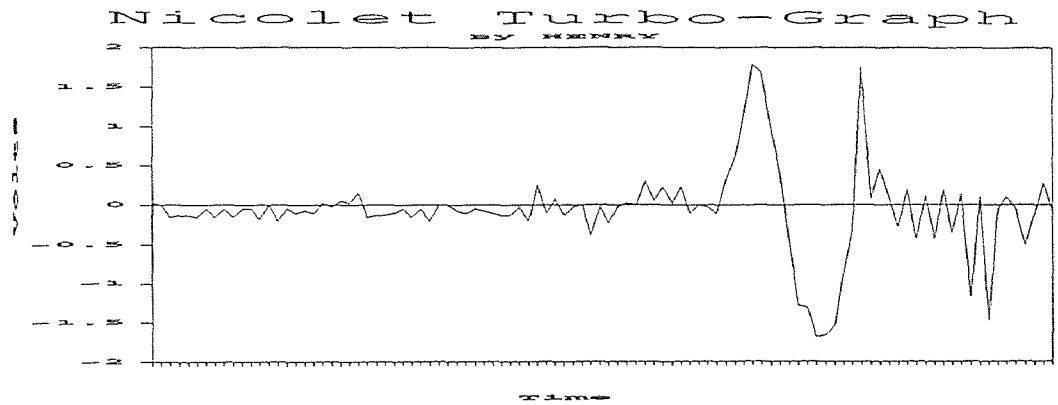
Pressure : 50,000 Psi
Stand Off Distance : 0.5 mm
Data : 30 Set
Time Base : 50n Sec

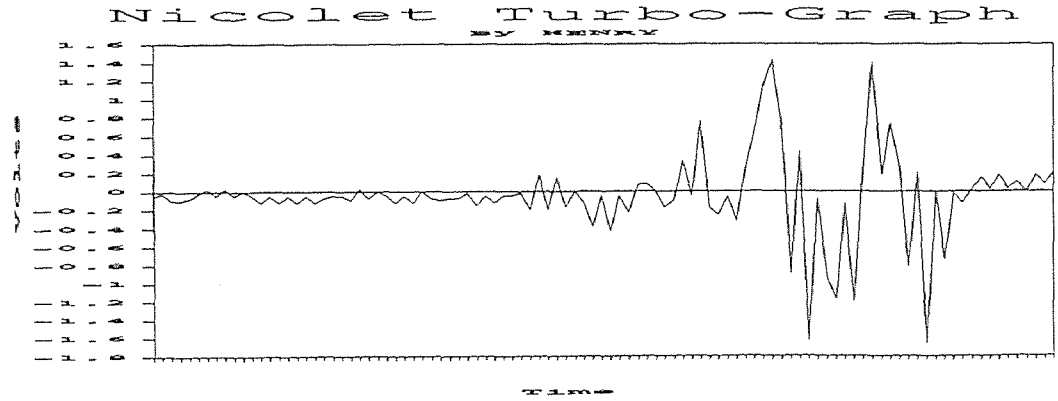
STATISTICS ANALYSIS
Sample Size : 30
Minimum = 690.77
maximum = 898
Range = 207.23
Median = 816.36
Arithmetic Mean = 787.3697
Geometric Mean = 785.2552
Variance = 3431.937
Standard Deviation = 58.58274
Coefficient of Variation = 7.440309 %
Skewness : Bata (1) = 2.018591E-03 (+)
Kurtosis : Beta (2) = 2.42554

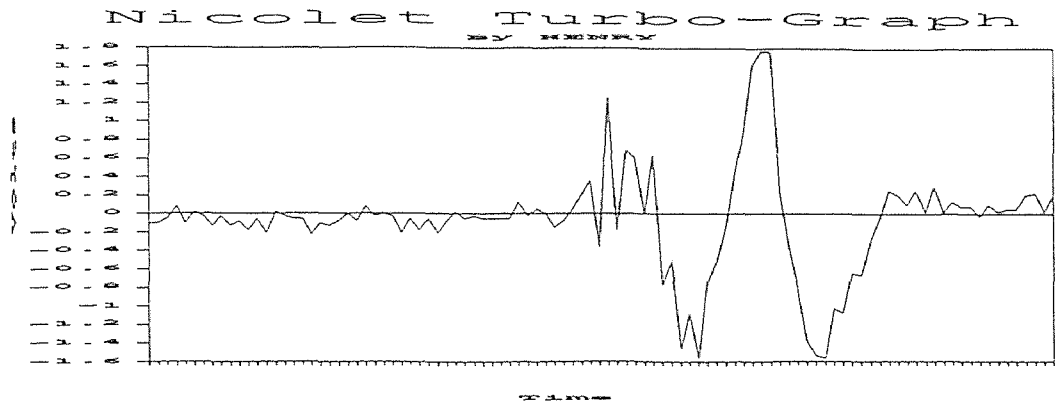


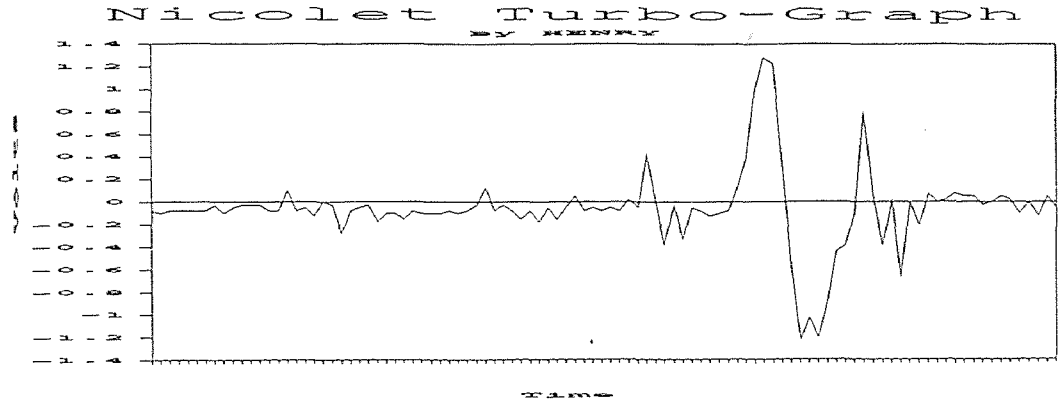

Nicolet Turbo-Graph
by HENRY
time

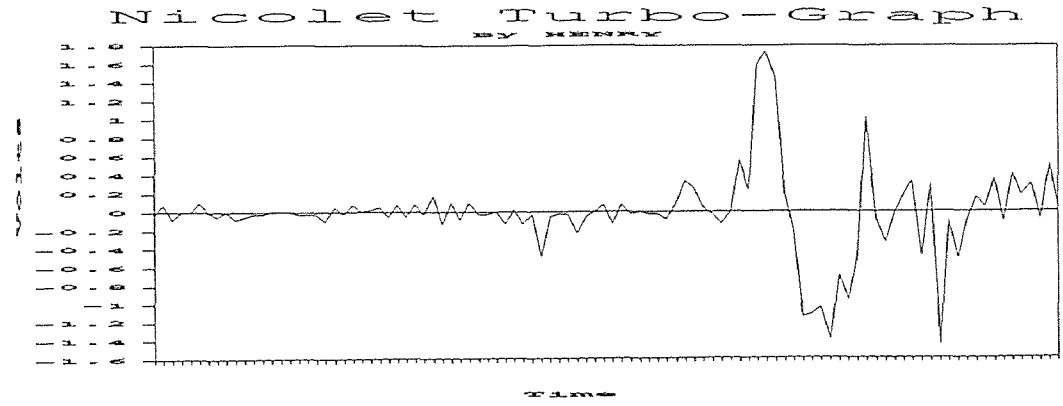

Nicolet Turbo-Graph
by HENRY
time

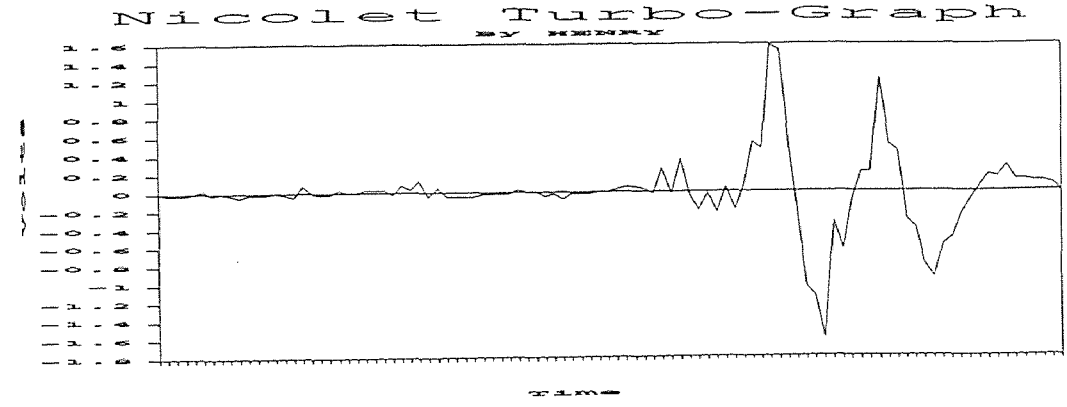

Nicolet Turbo-Graph
by HENRY
time

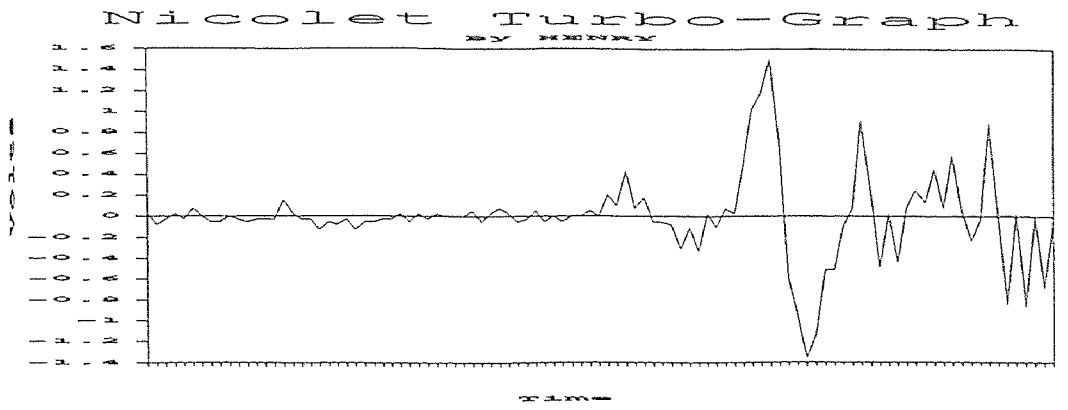

Nicolet Turbo-Graph
by HENRY
time

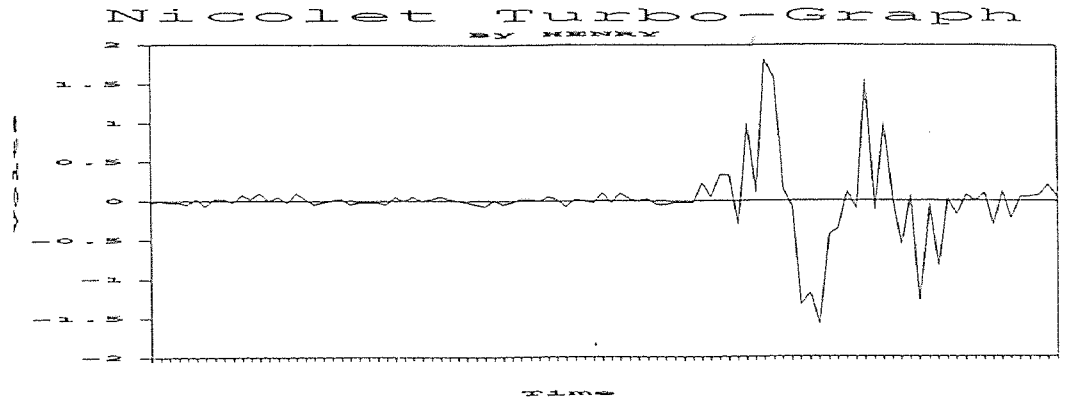

Nicolet Turbo-Graph
by HENRY
time

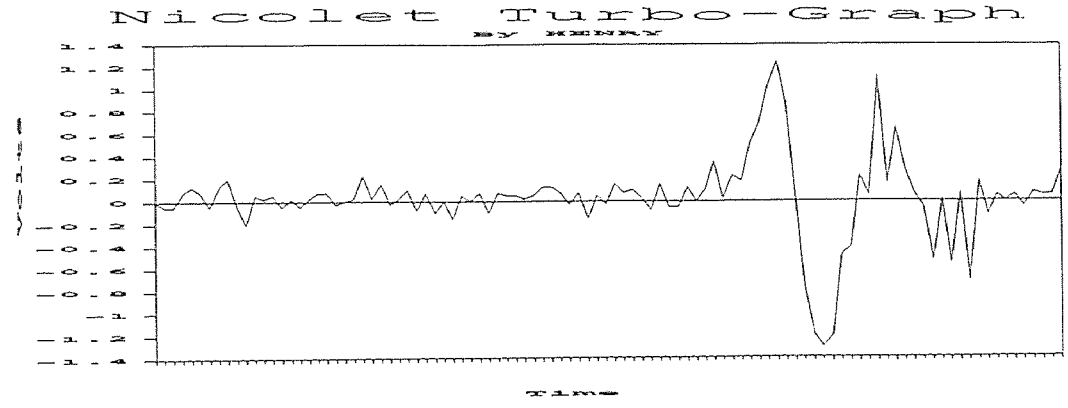

Nicolet Turbo-Graph
by HENRY
time

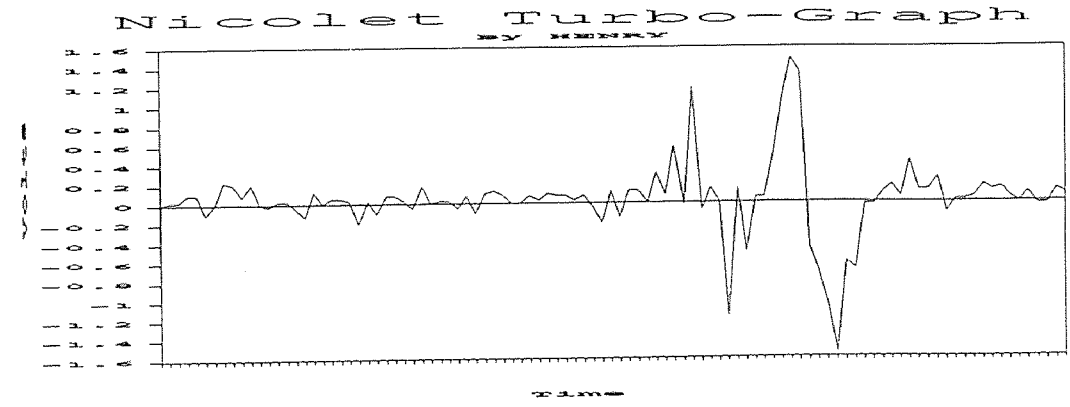

Nicolet Turbo-Graph
by HENRY
time

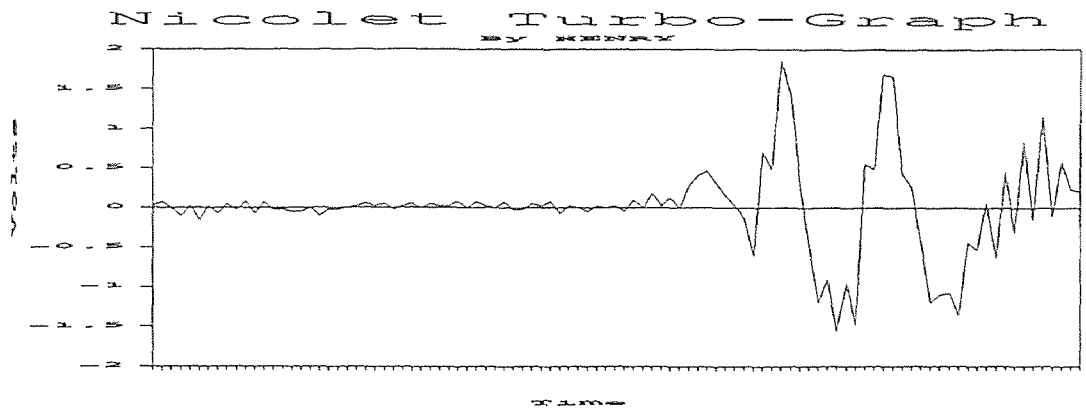

Nicolet Turbo-Graph
by HENRY
time

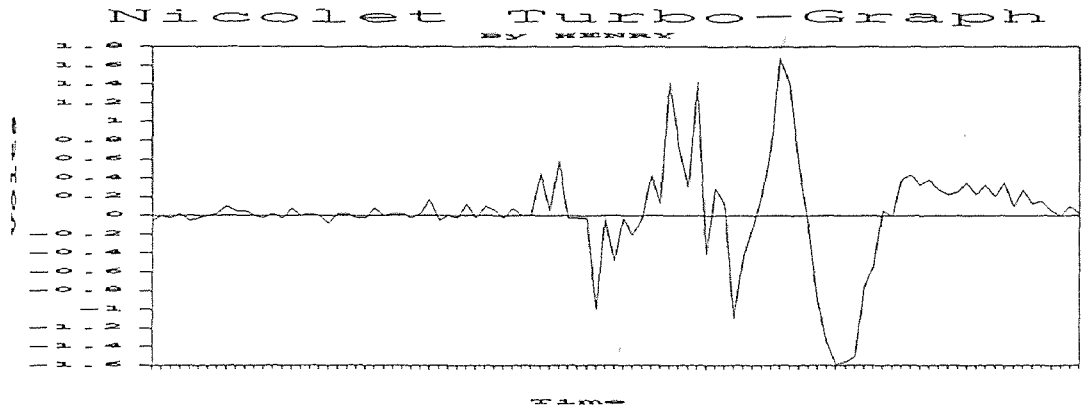

Nicolet Turbo-Graph
by HENRY
time

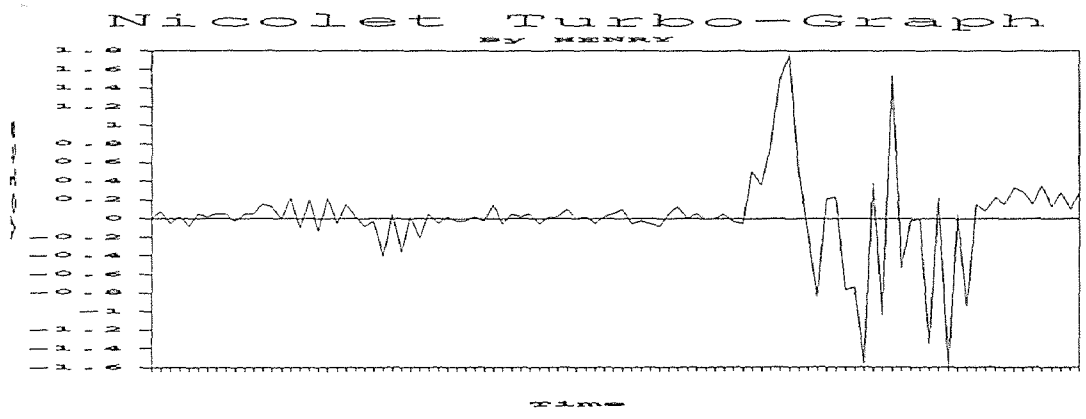

Nicolet Turbo-Graph
by HENRY
time

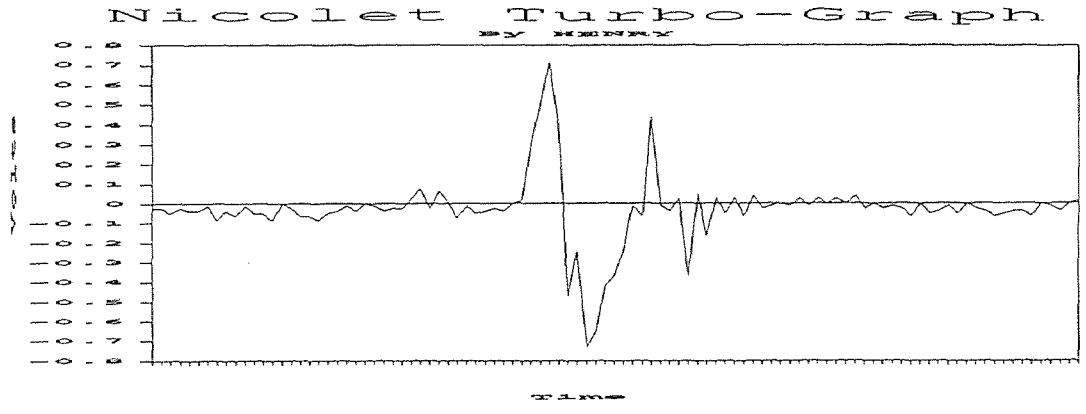

Nicolet Turbo-Graph
by HENRY
time


Nicolet Turbo-Graph
by HENRY
time


Nicolet Turbo-Graph
by HENRY
time


Nicolet Turbo-Graph
by HENRY
time


Nicolet Turbo-Graph
by HENRY
time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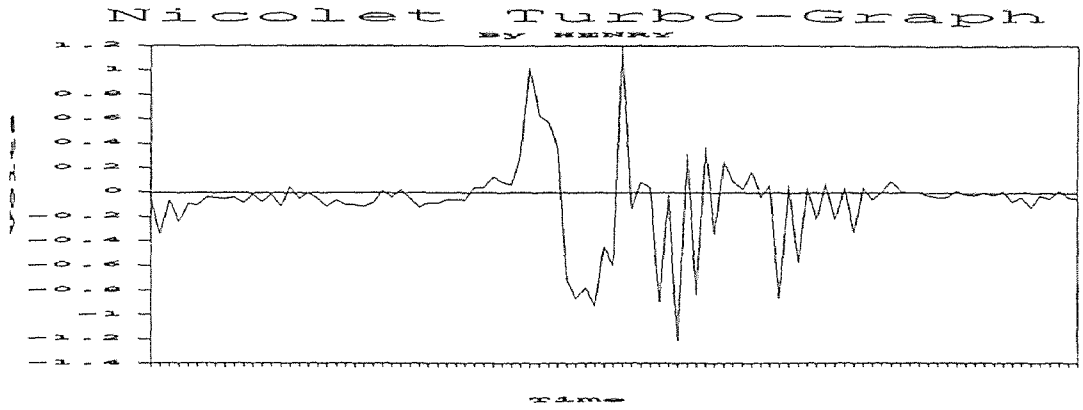
by HENRY
time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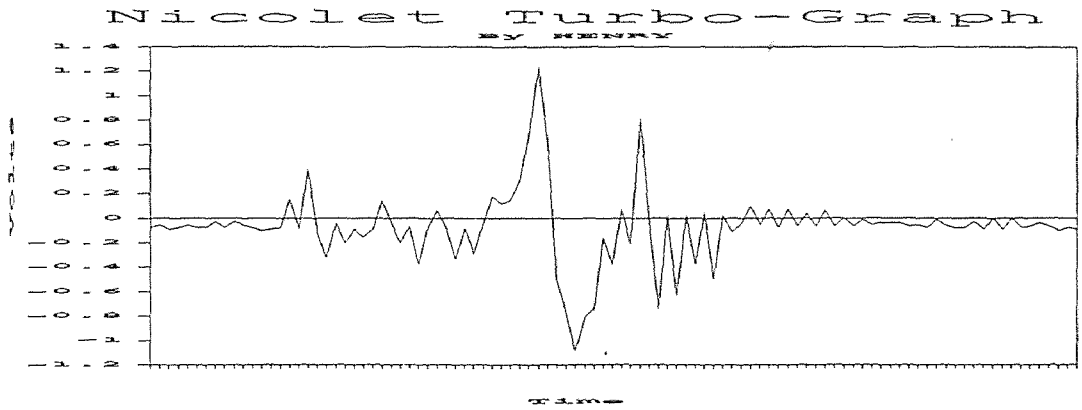
by HENRY
time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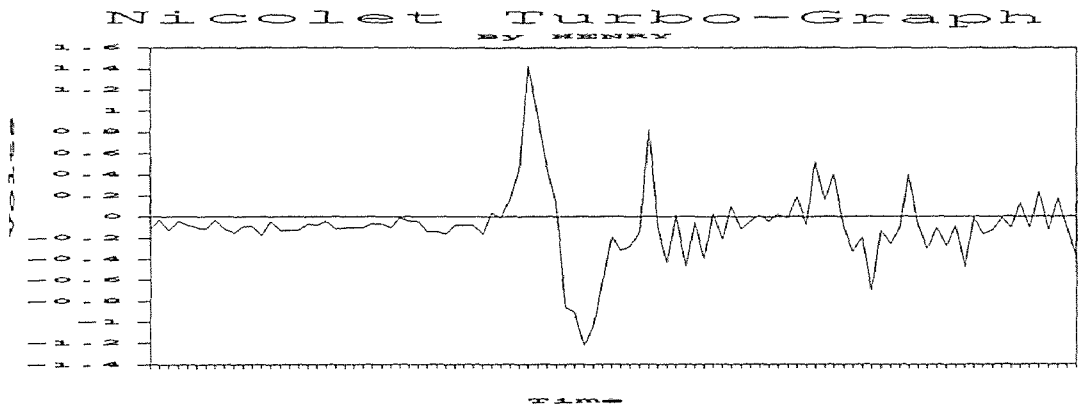
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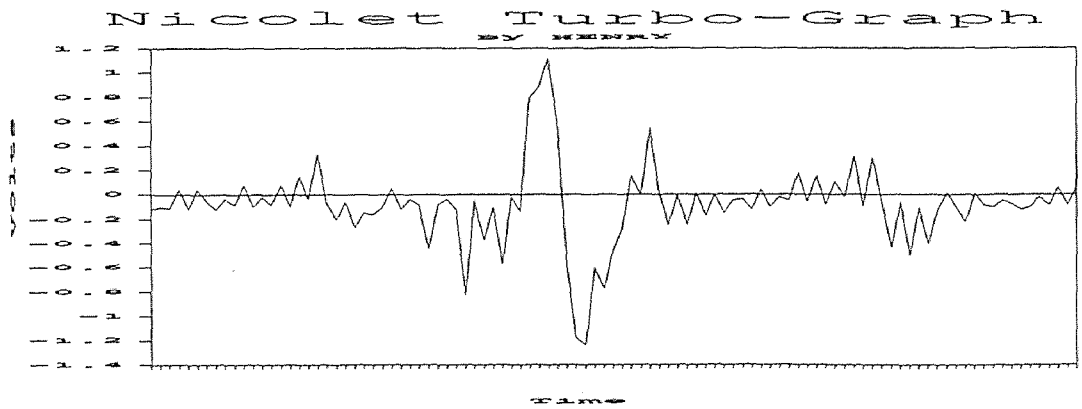
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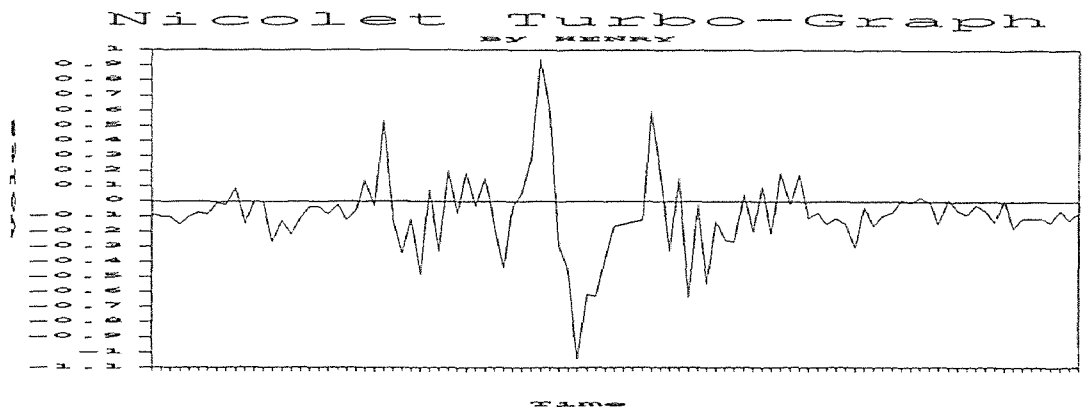
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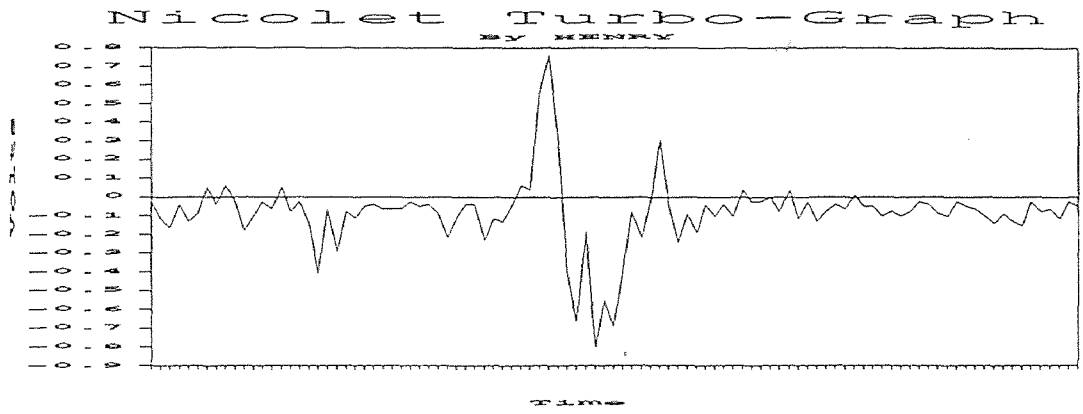
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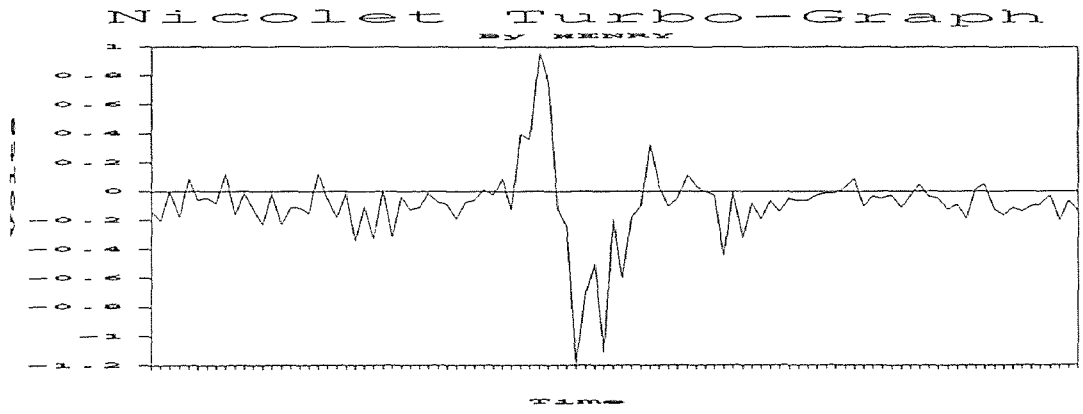
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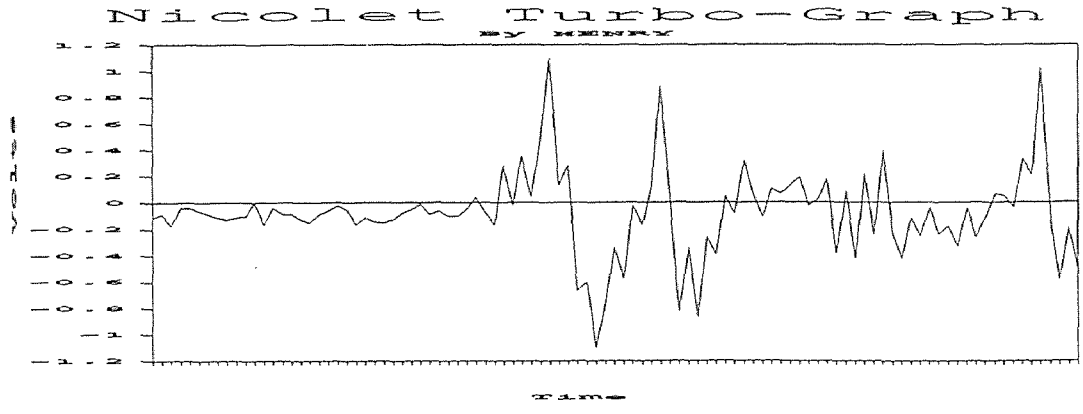
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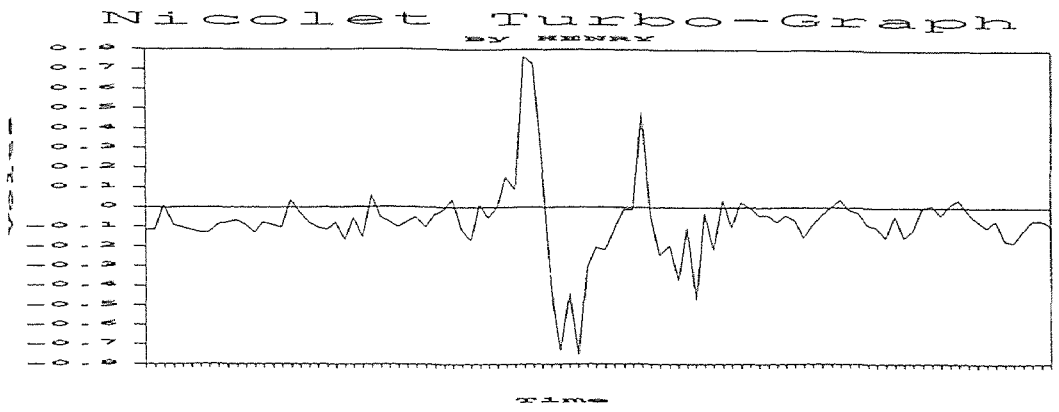
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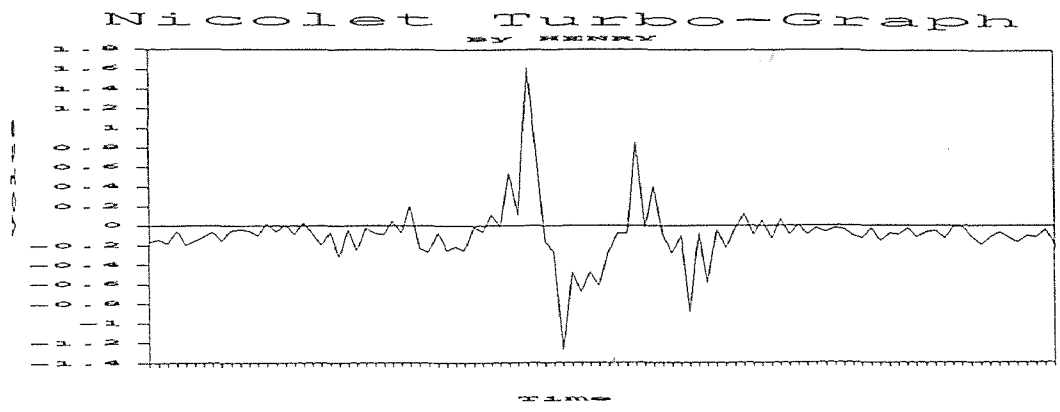
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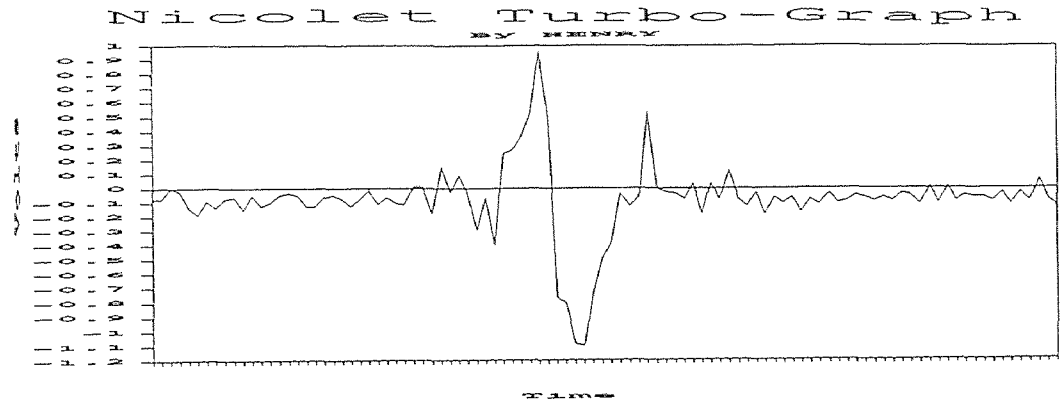
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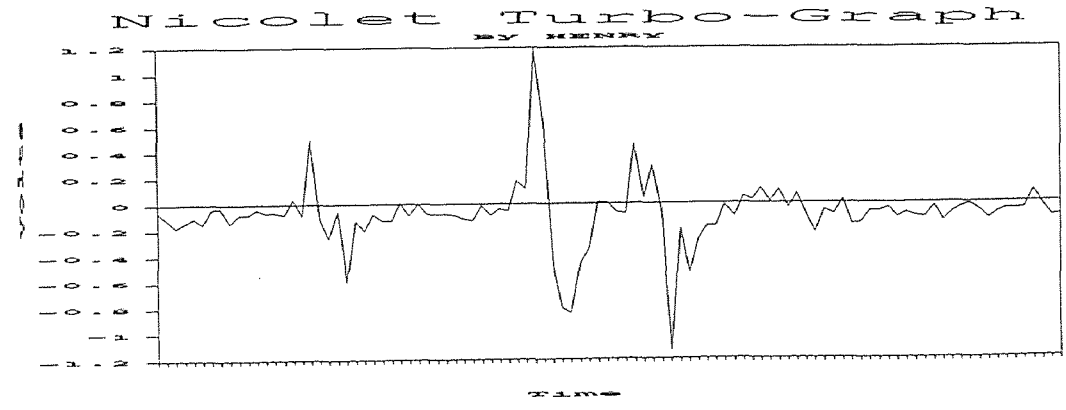
time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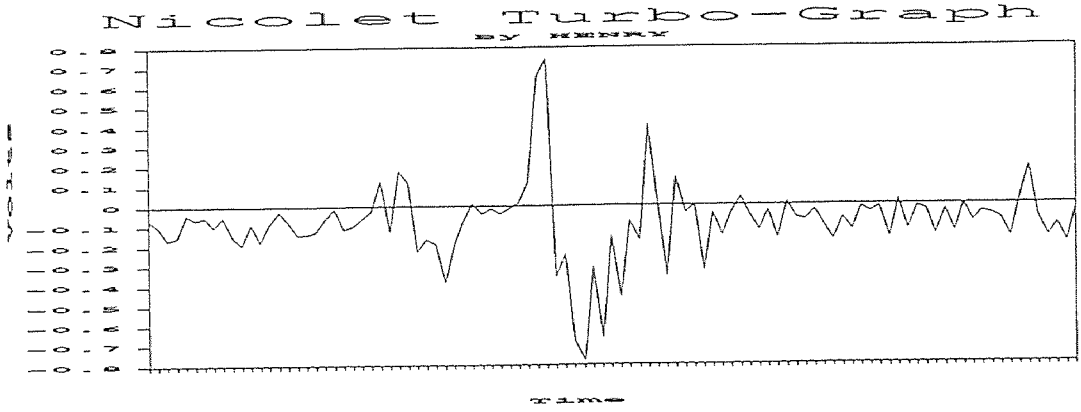
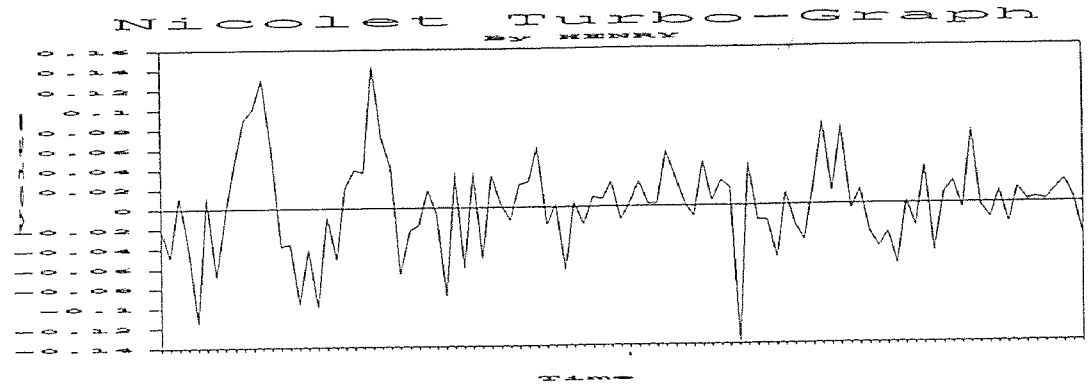

Nicolet Turbo-Graph
by HENRY
time

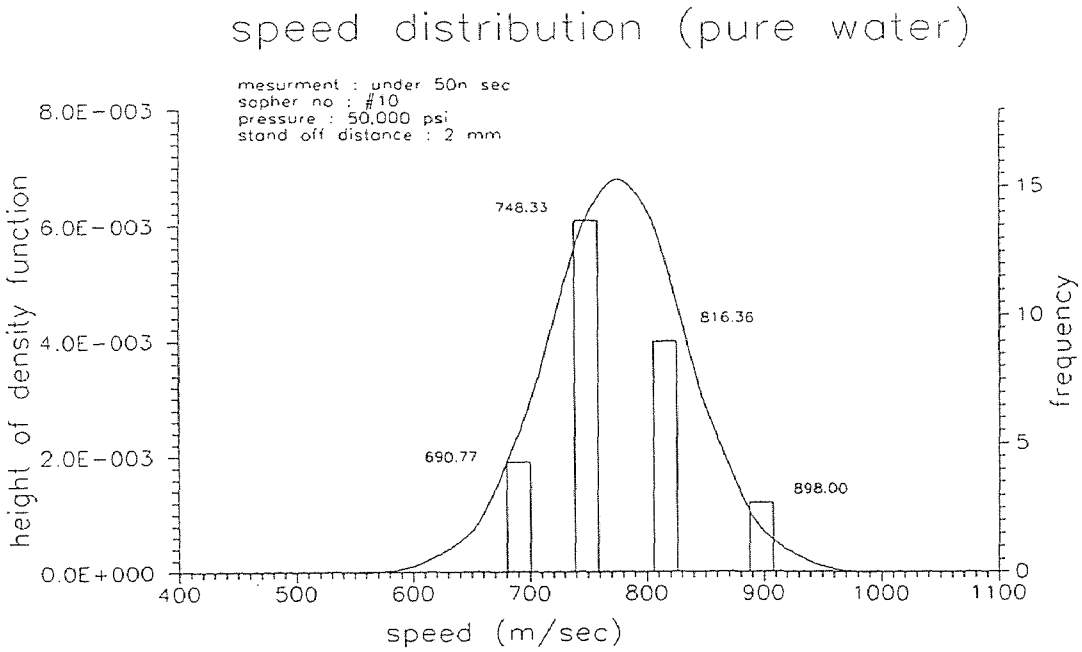

Nicolet Turbo-Graph
by HENRY
time

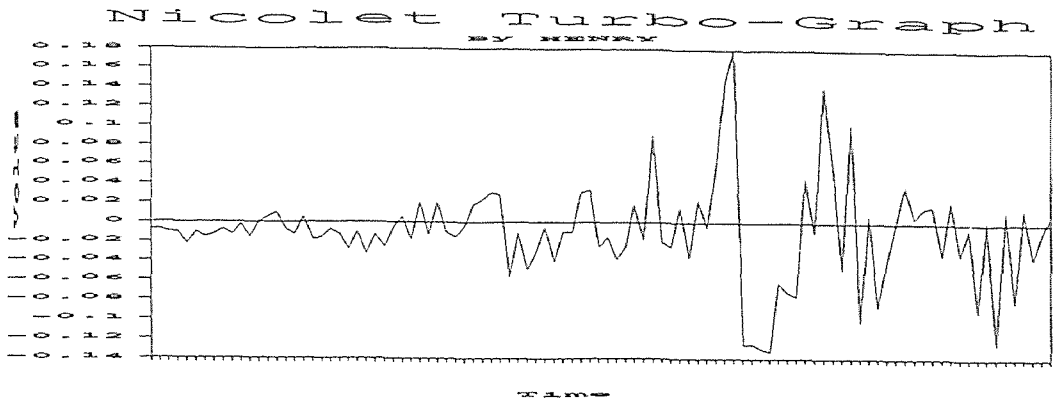
WATER JET VELOCITIES MESUREMENT

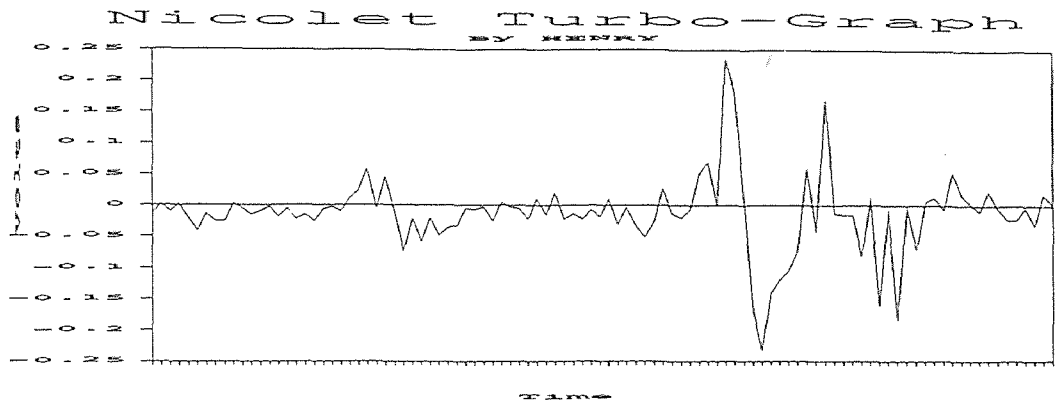
(PURE WATER)

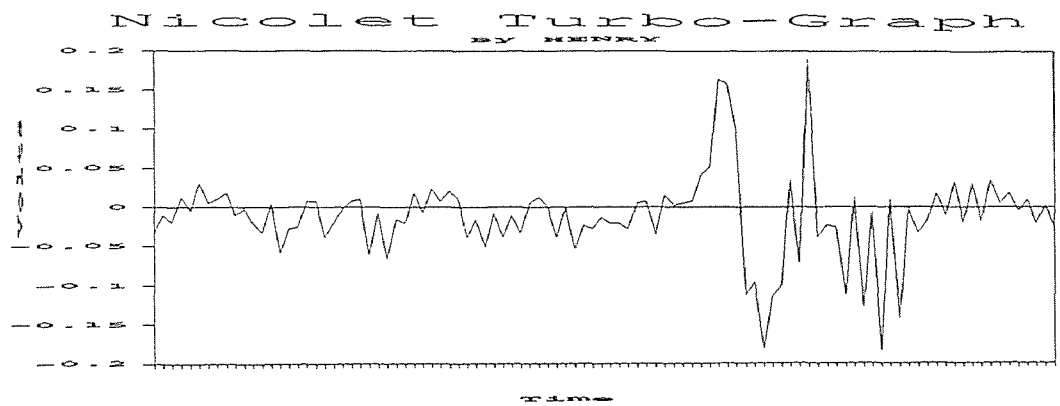
Pressure : 50,000 Psi
Stand Off Distance : 2 mm
Data : 30 Set
Time Base : 50n Sec

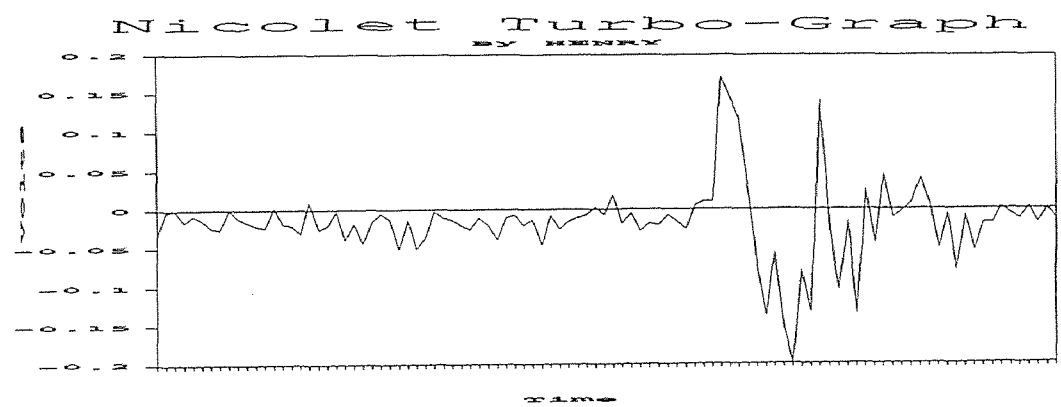
STATISTICS ANALYSIS
Sample Size : 30
Minimum = 690.76
maximum = 898
Range = 207.24
Median = 748.33
Arithmetic Mean = 776.0313
Geometric Mean = 773.9497
Variance = 3416.818
Standard Deviation = 58.45356
Coefficient of Variation = 7.532371 %
Skewness : Bata (1) = 0.3161788 (+)
Kurtosis : Beta (2) = 2.679992




Nicolet Turbo-Graph
by HENRY
time


Nicolet Turbo-Graph
by HENRY
time


Nicolet Turbo-Graph
by HENRY
time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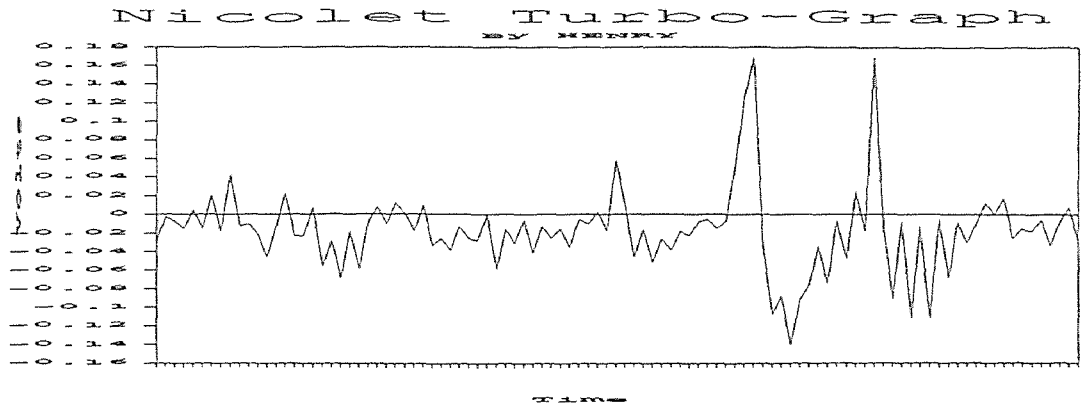
by HENRY
time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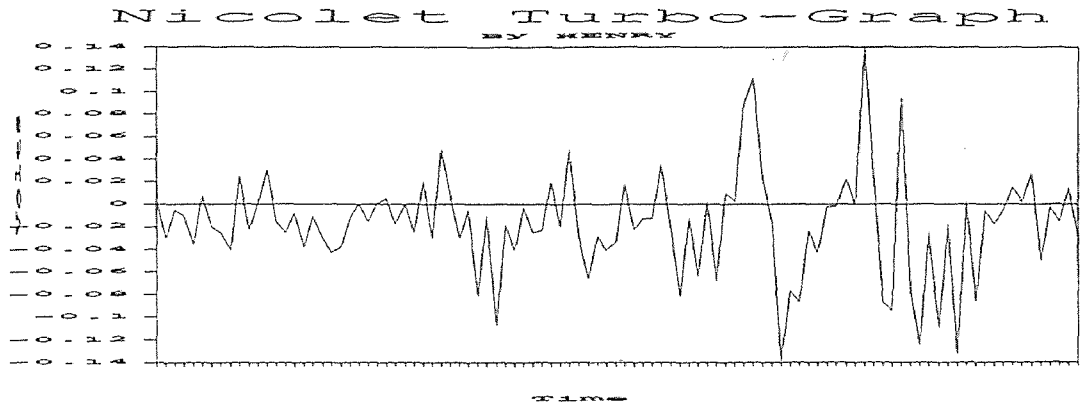
by HENRY
time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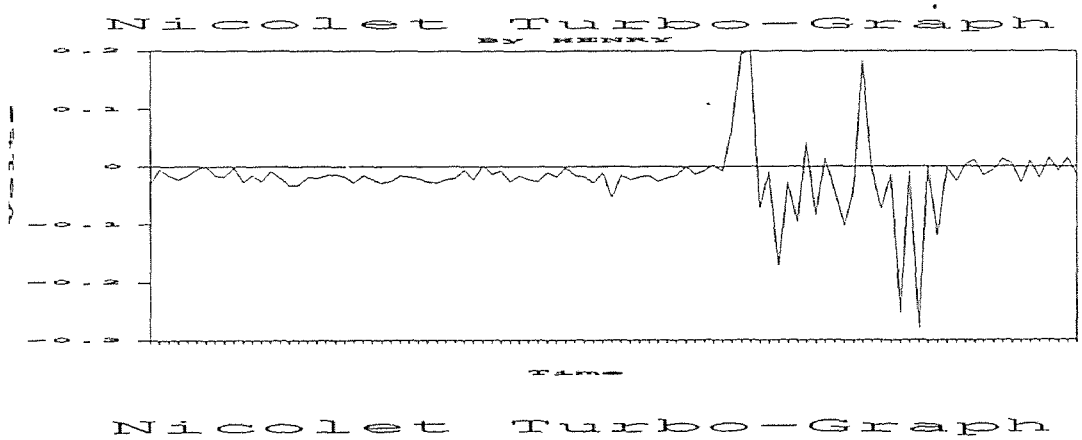
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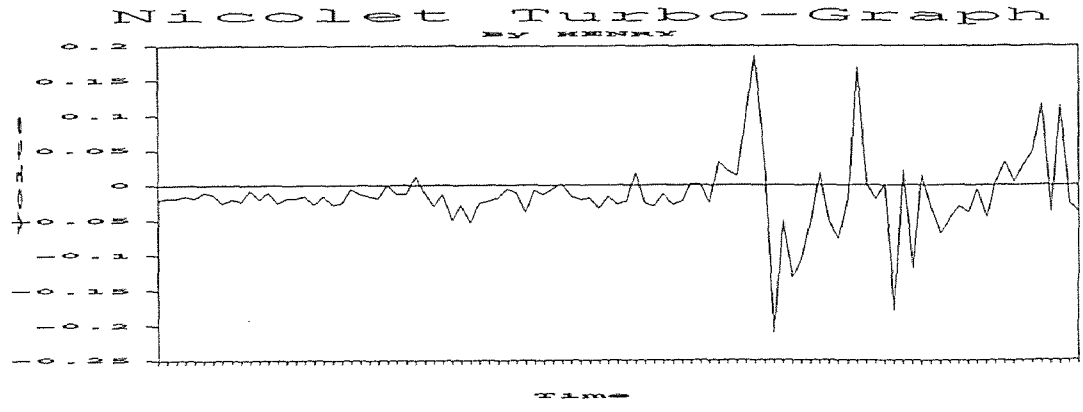
by HENRY
time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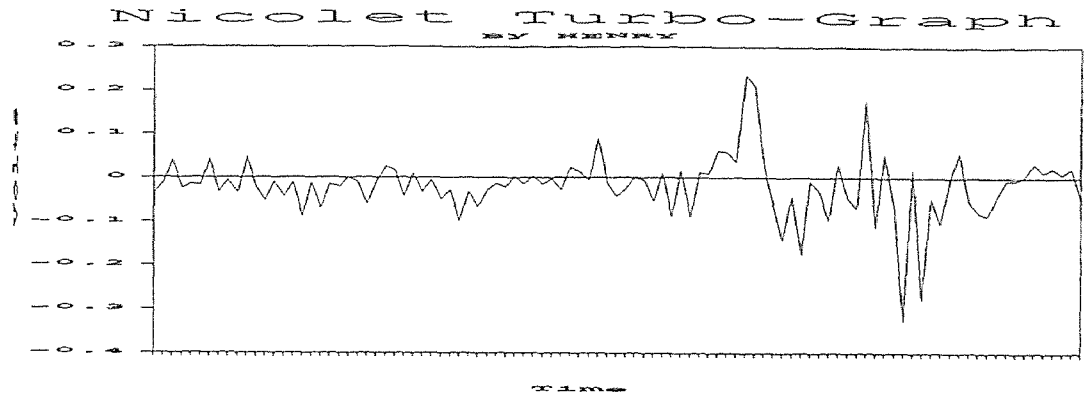
by HENRY
time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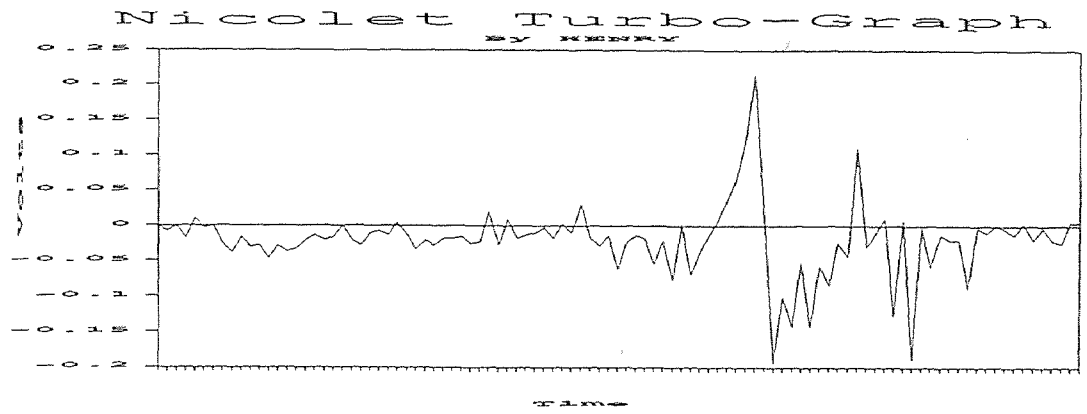
by Henry
time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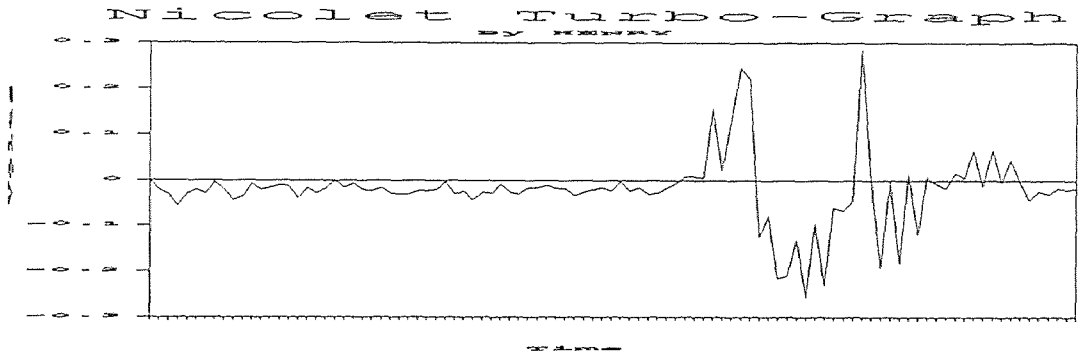
by Henry
time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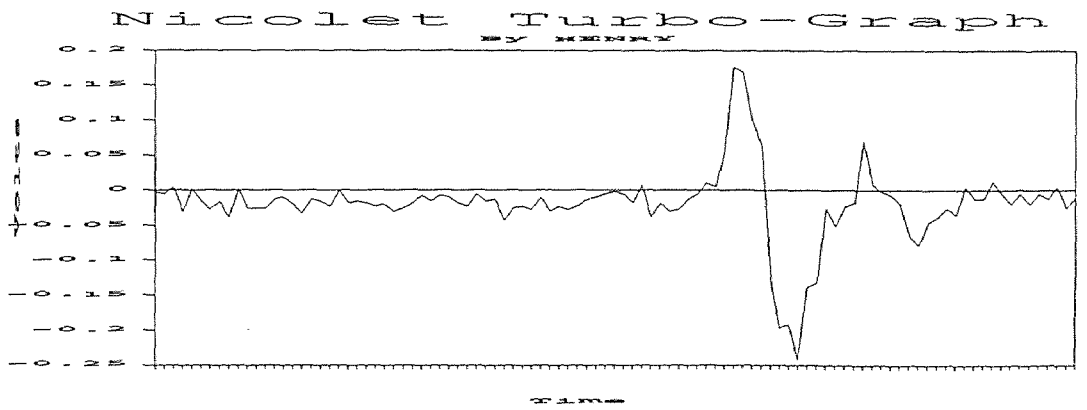
by Henry
time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by Henry
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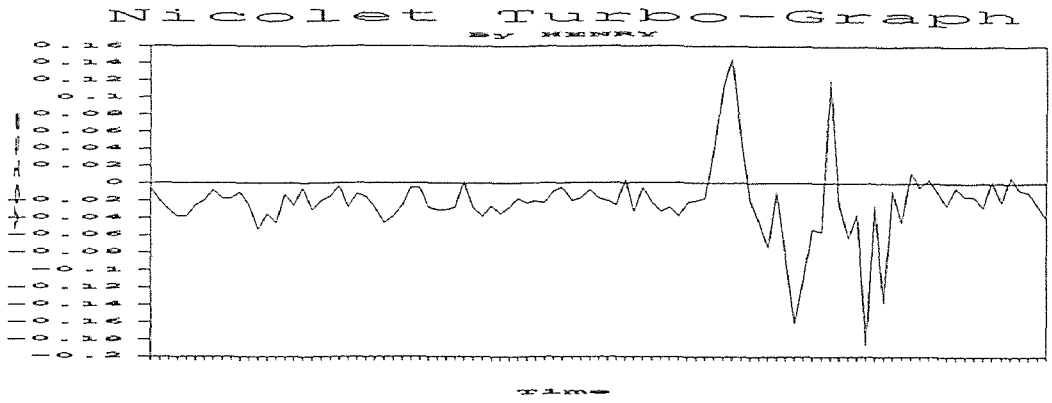
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by HENRY
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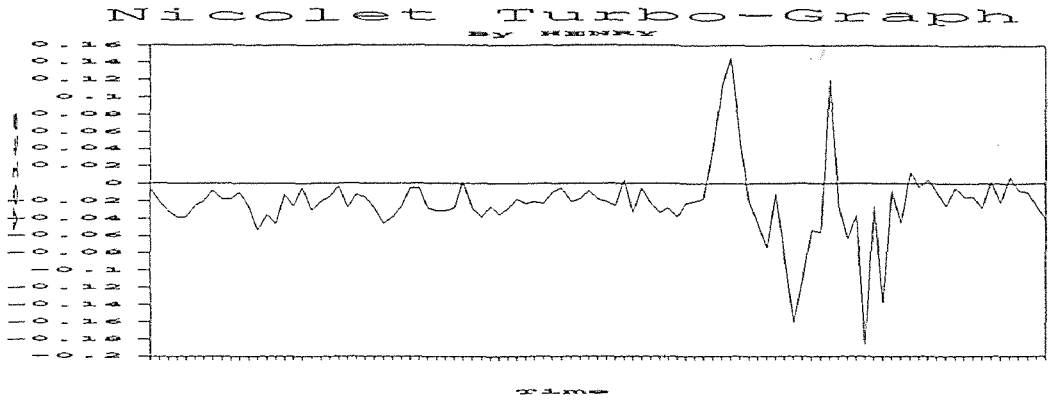
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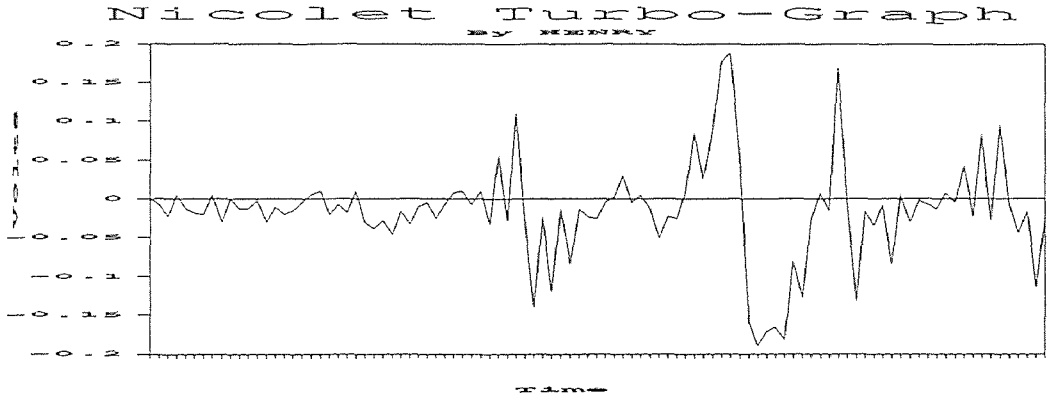
by HENRY
time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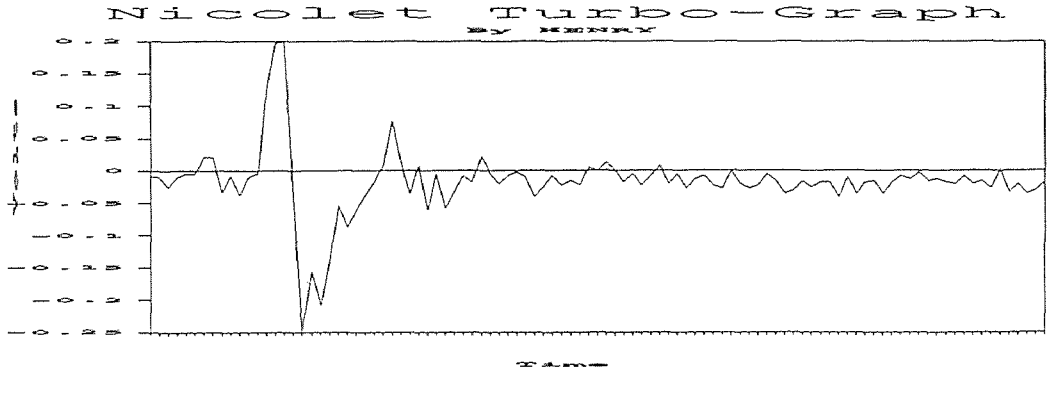
by HENRY
time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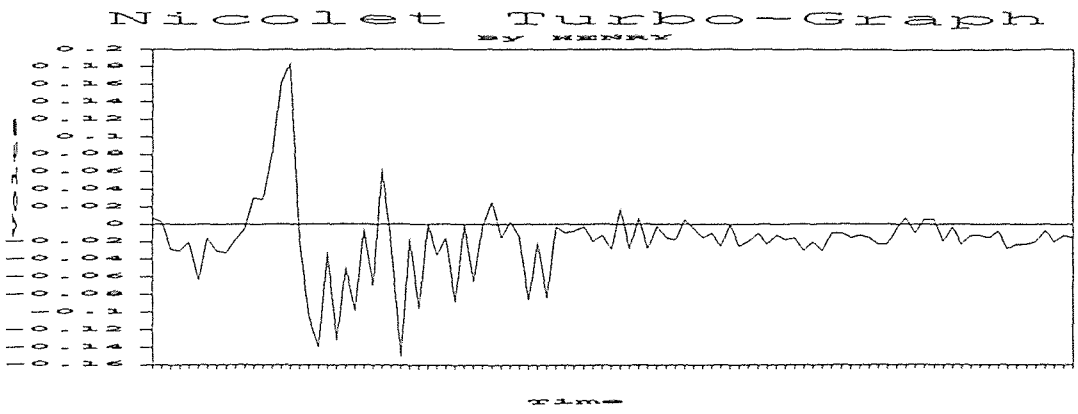
by HENRY
time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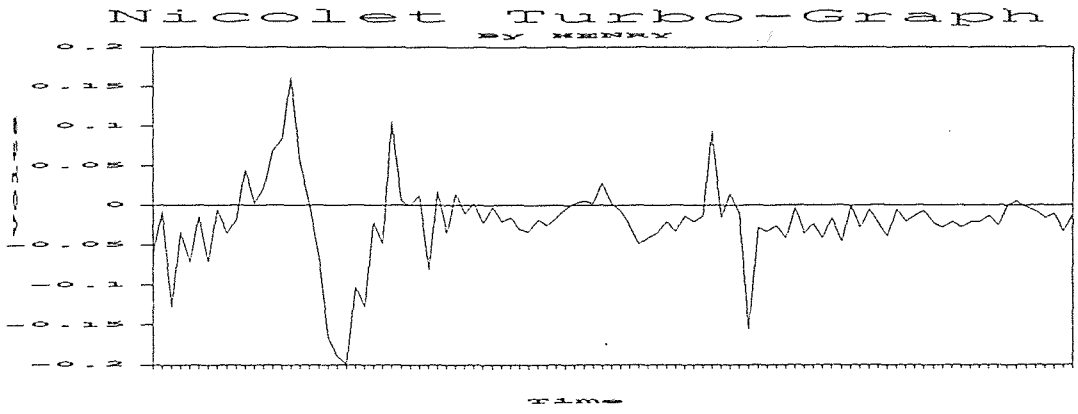
by Henry
time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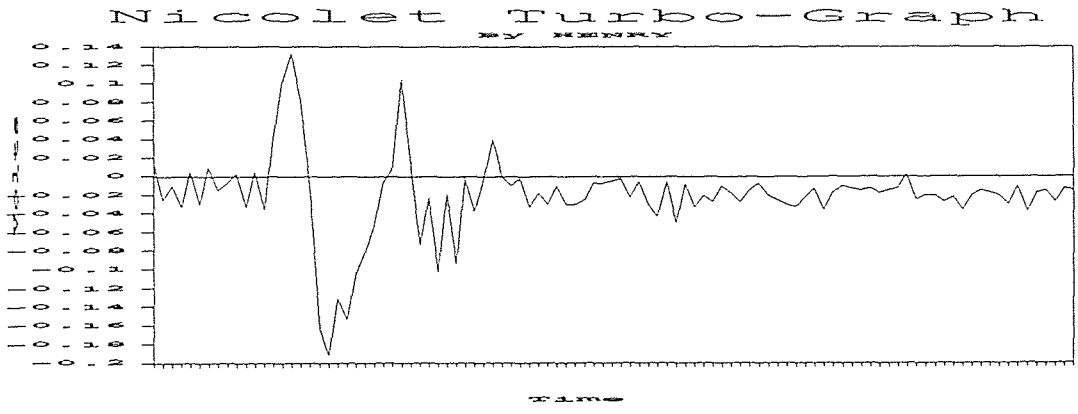
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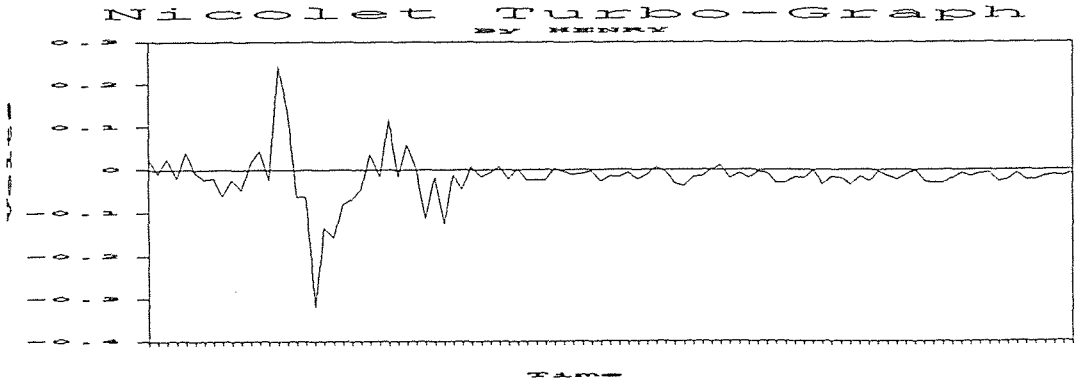
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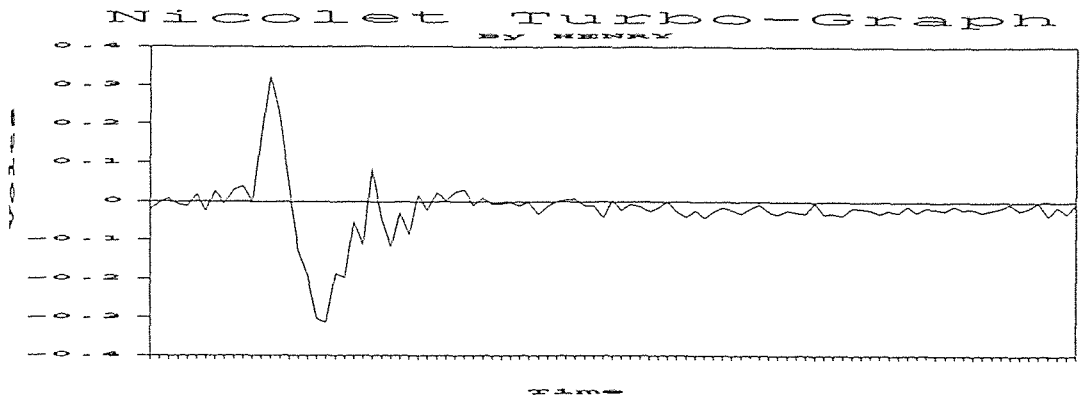
by Henry
time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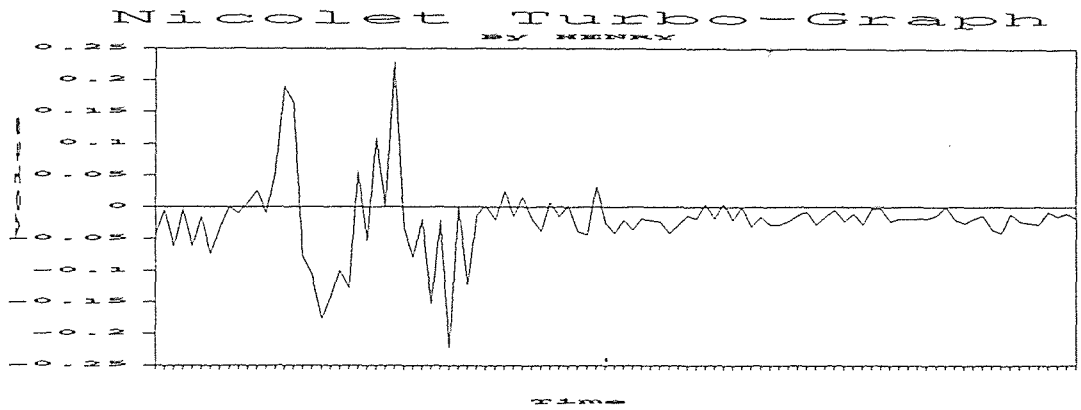
by Henry
volts
time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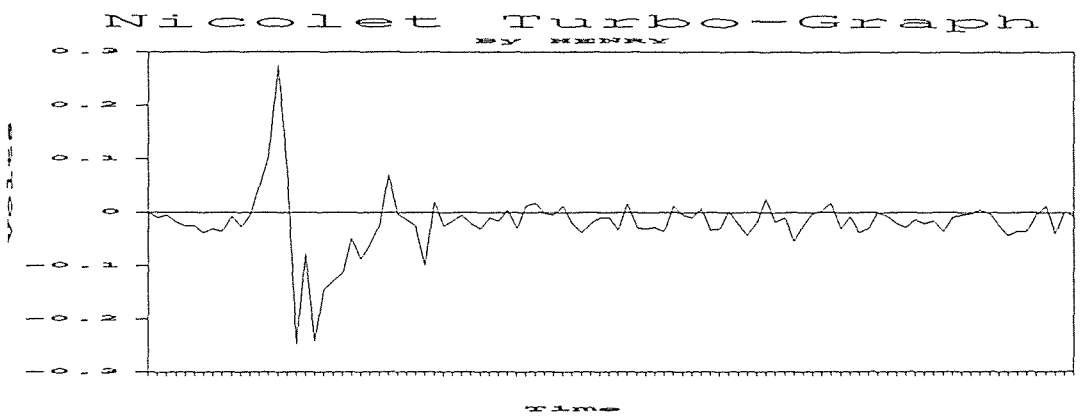
by Henry
volts
time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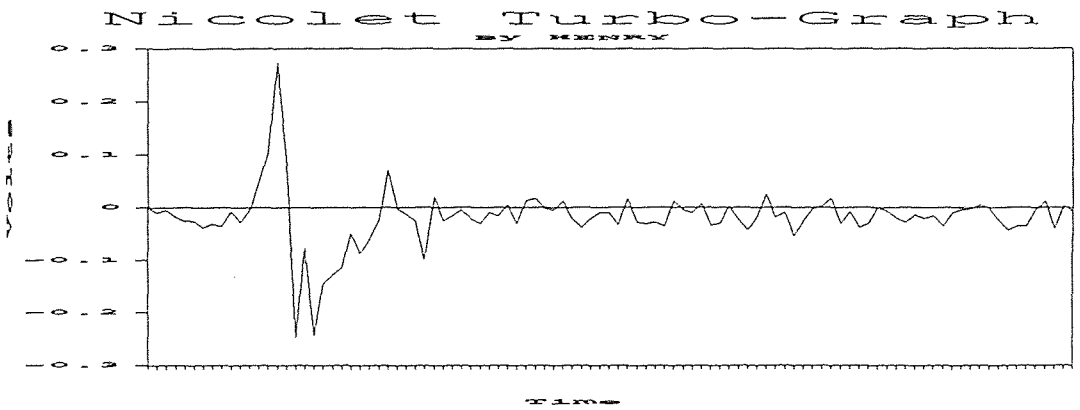
by Henry
volts
time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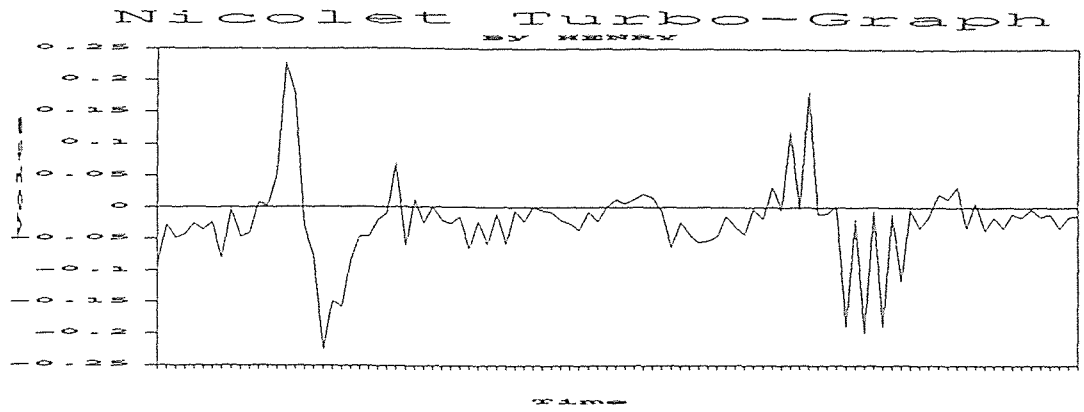
by Henry
volts
time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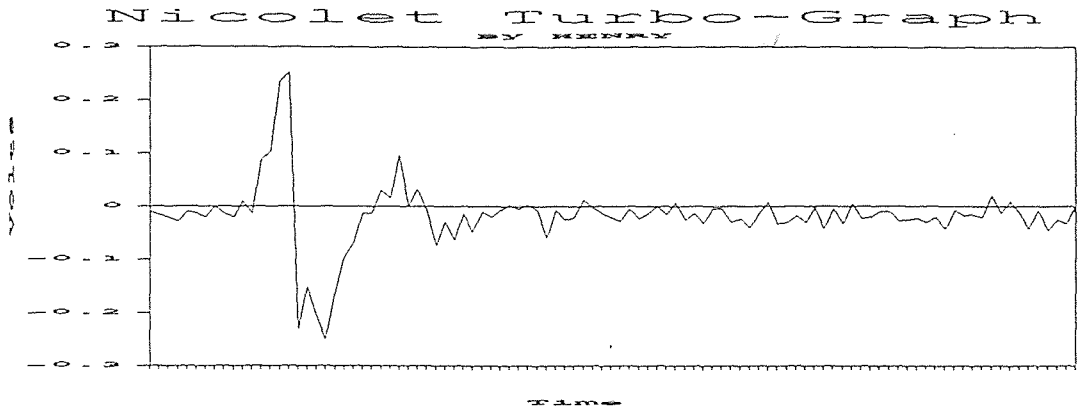
by Henry
time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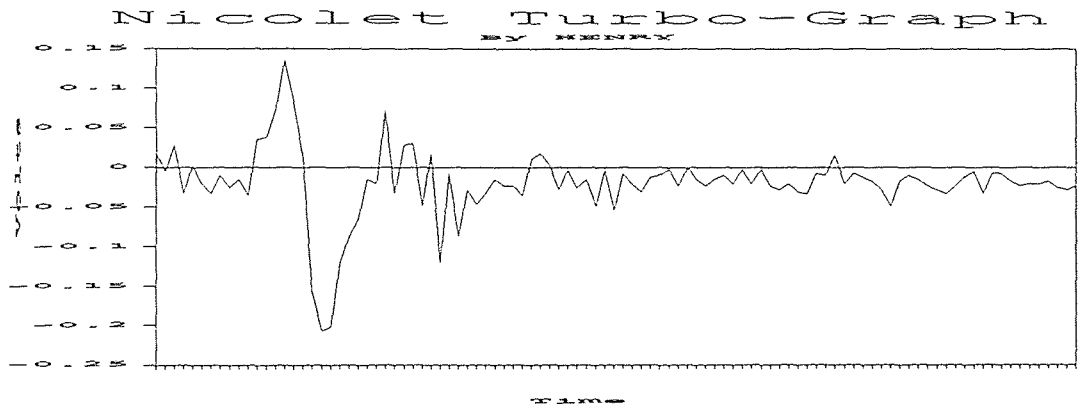
by Henry
time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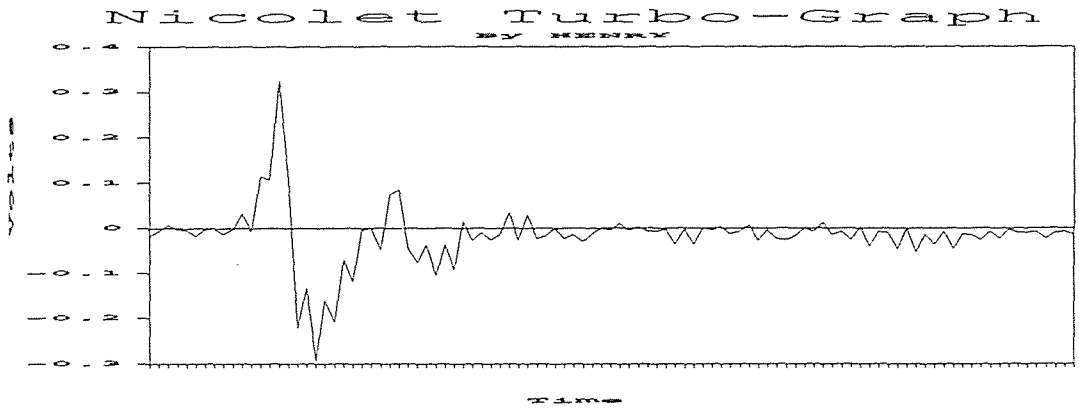
by Henry
time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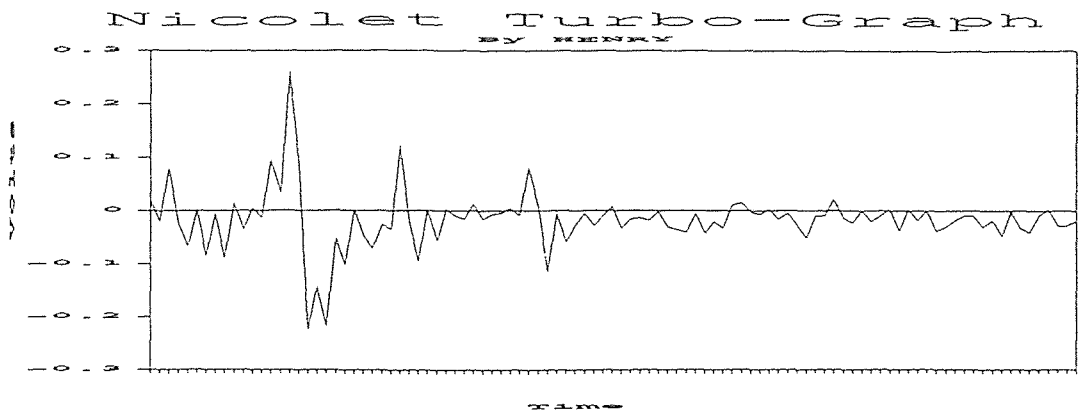
by Henry
time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by HENRY
0.3
0.2
0.1
0
-0.1
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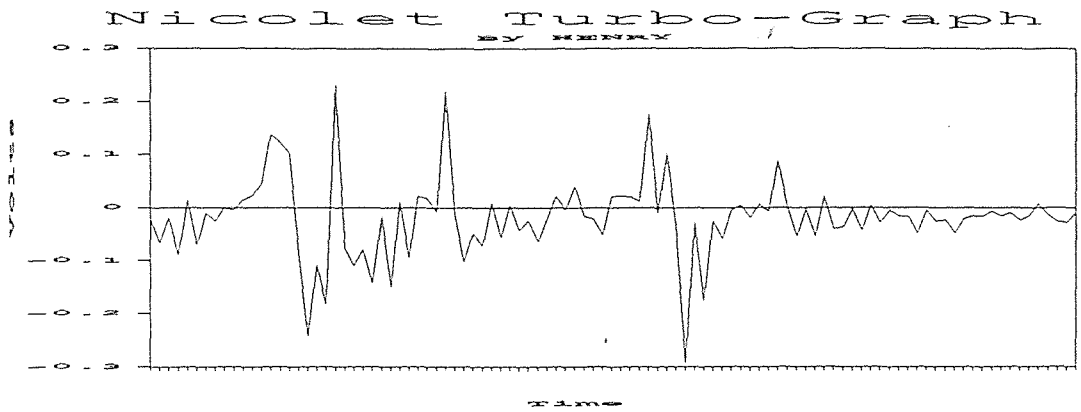
time

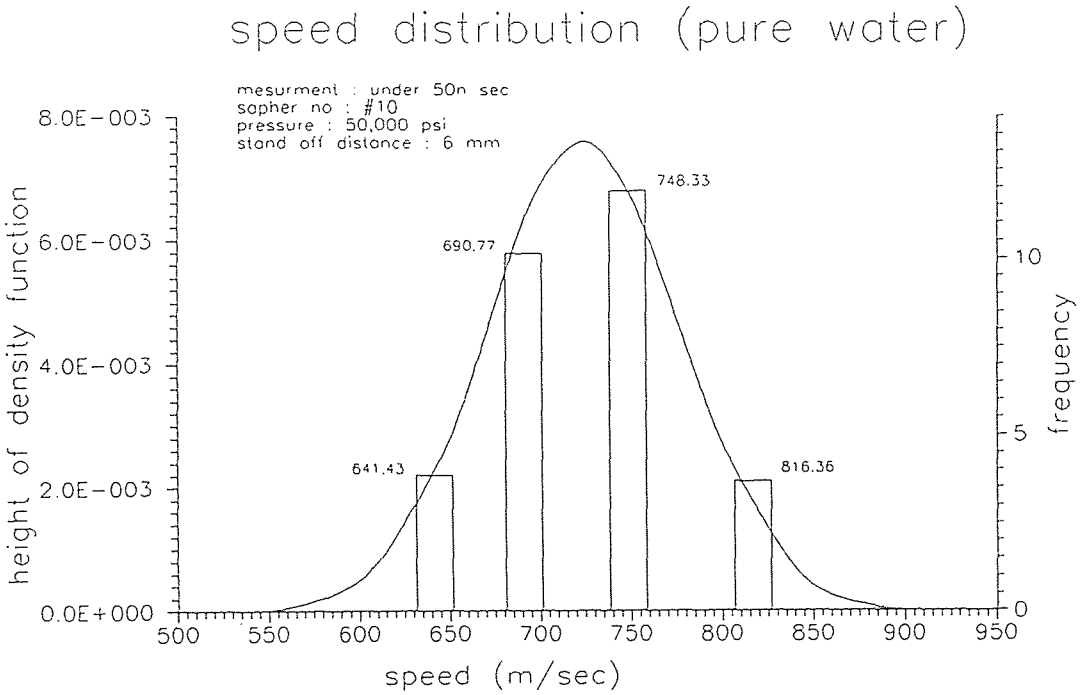

Nicolet Turbo-Graph
by HENRY
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
time

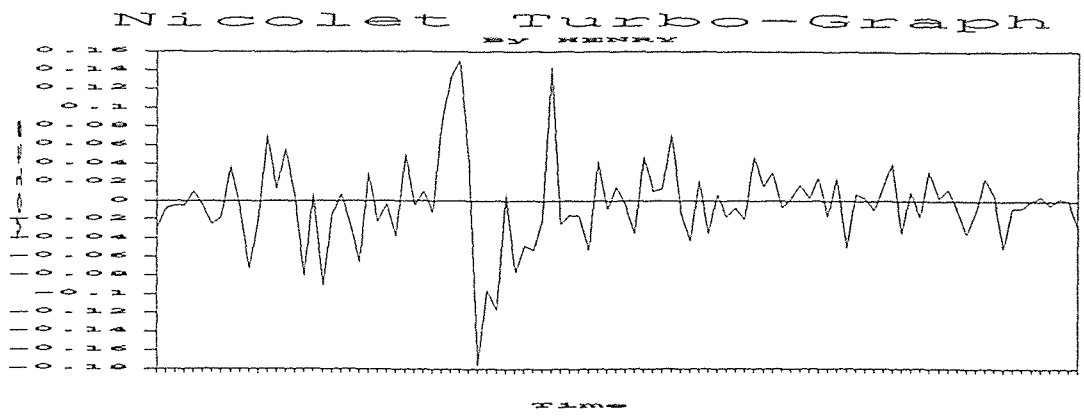
WATER JET VELOCITIES MESUREMENT

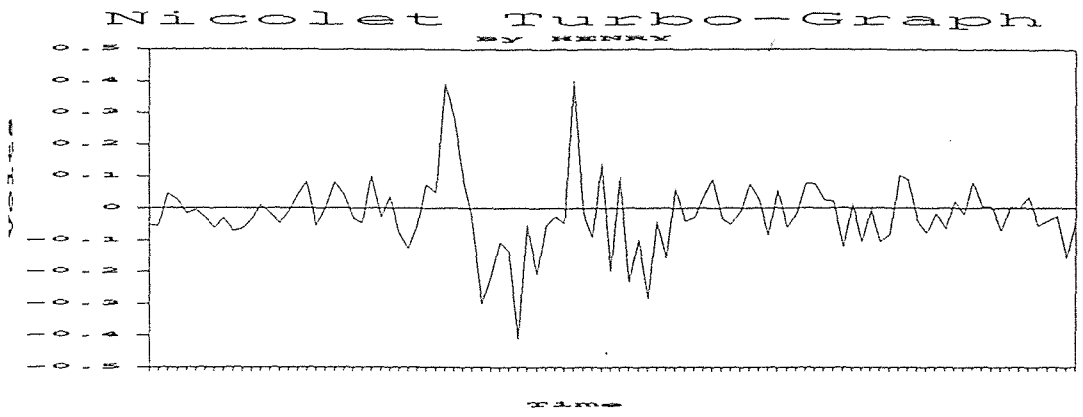
(PURE WATER)

Pressure : 50,000 Psi
Stand Off Distance : 6 mm
Data : 30 Set
Time Base : 50n Sec

STATISTICS ANALYSIS
Sample Size : 30
Minimum = 641.43
maximum = 816.36
Range = 174.93
Median = 748.33
Arithmetic Mean = 723.9606
Geometric Mean = 722.1357
Variance = 2742.702
Standard Deviation = 52.37082
Coefficient of Variation = 7.233931 %
Skewness : Bata (1) = 2.945979E-02 (+)
Kurtosis : Beta (2) = 2.262243




Nicolet Turbo-Graph
by HENRY
time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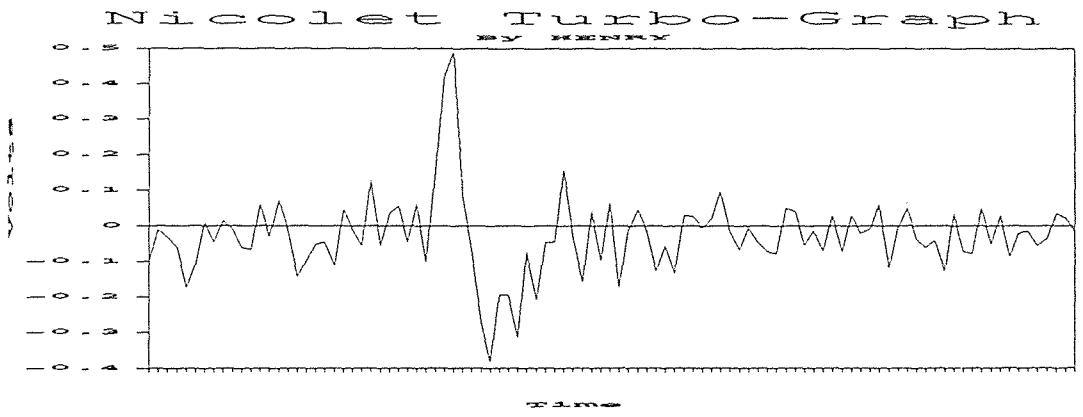
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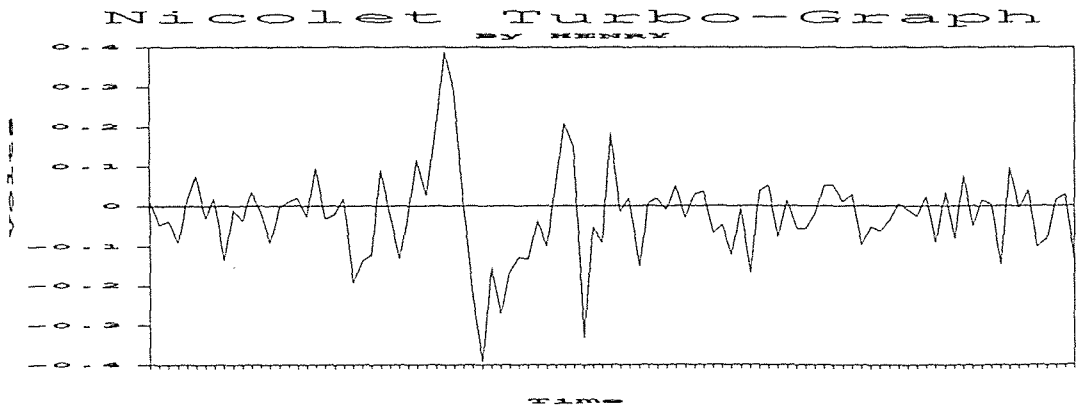
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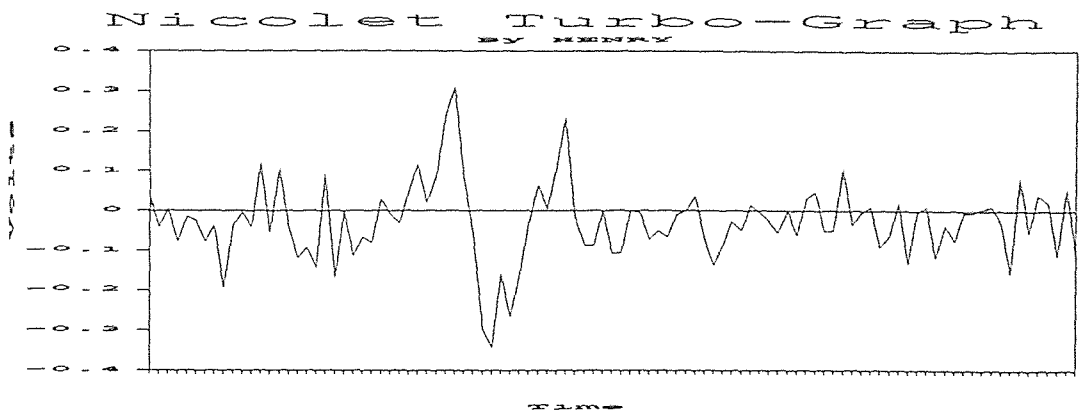
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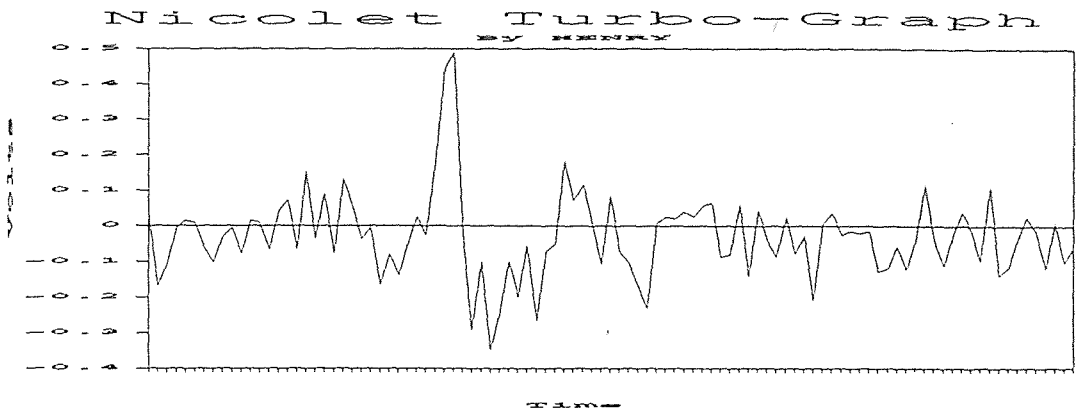
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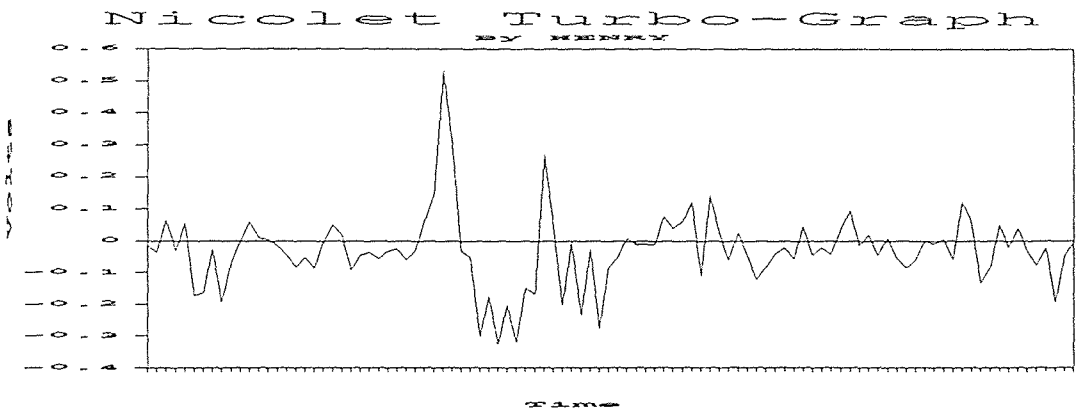
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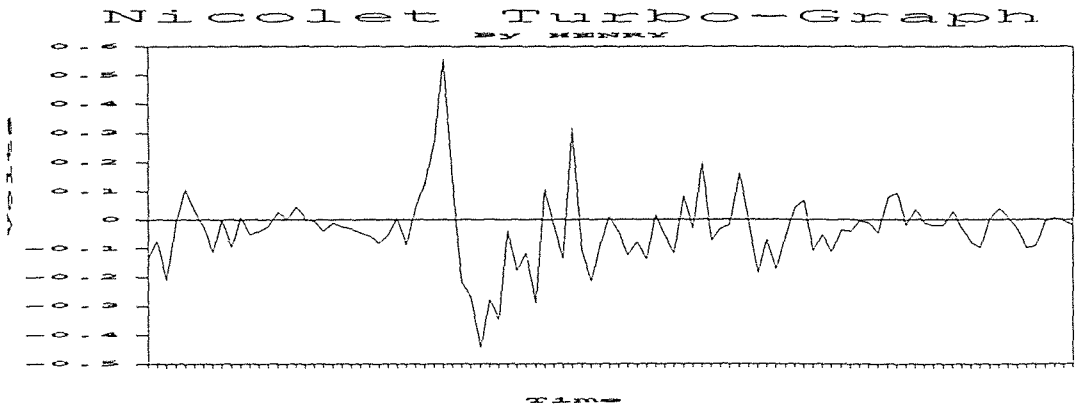
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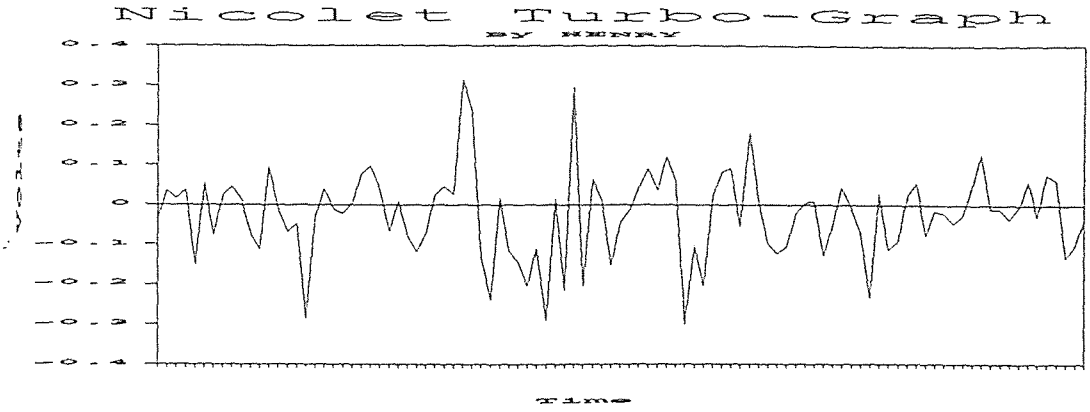
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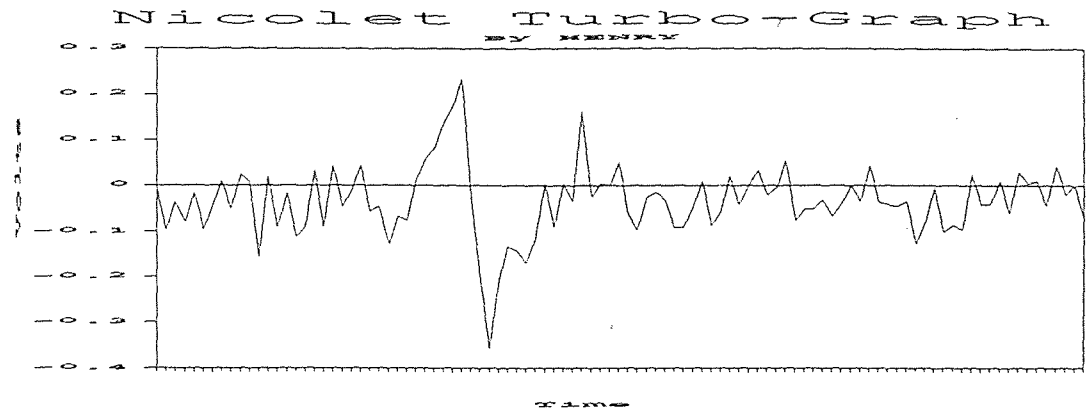
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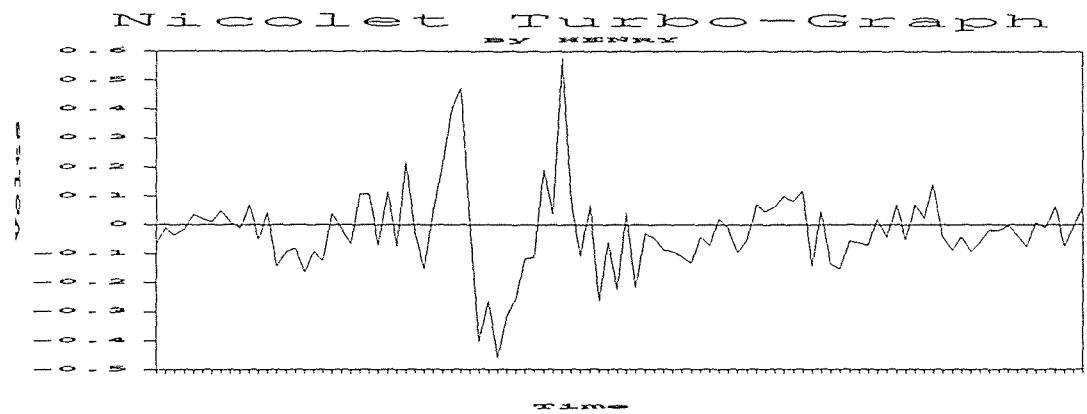
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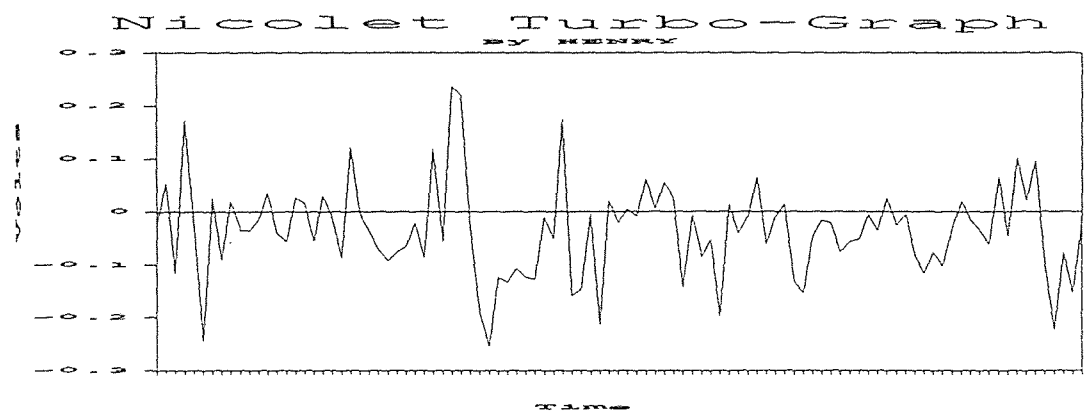
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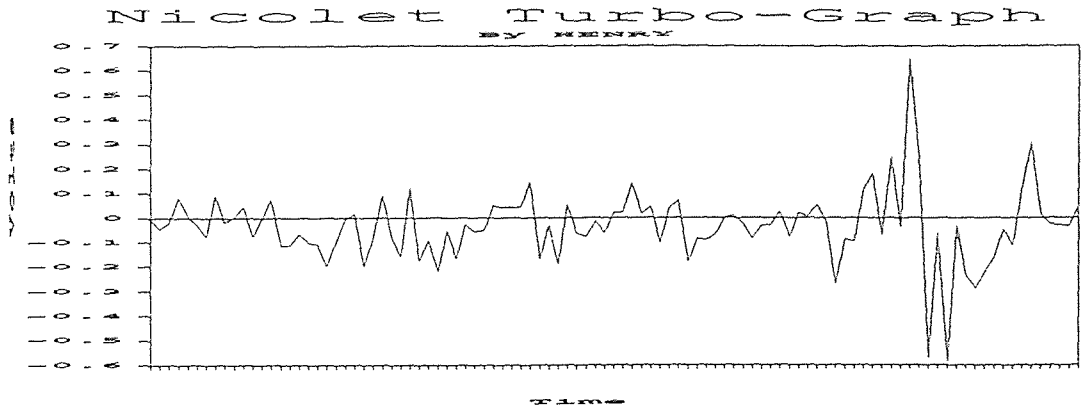
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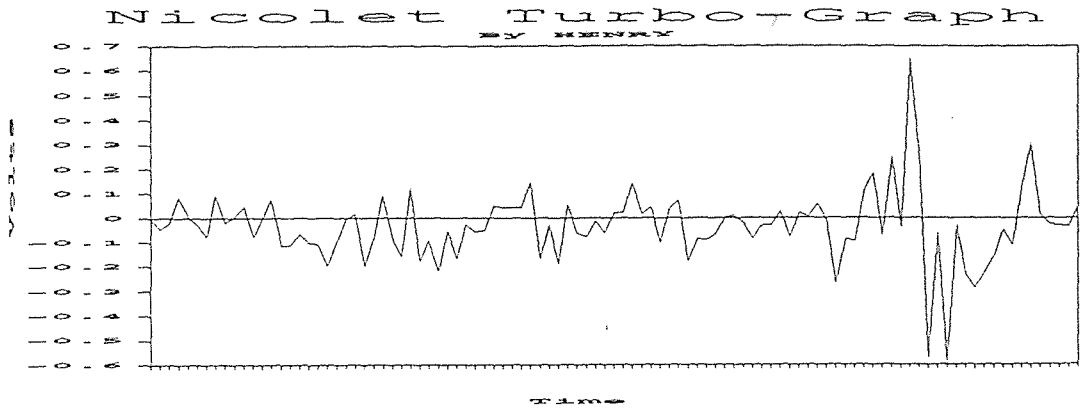
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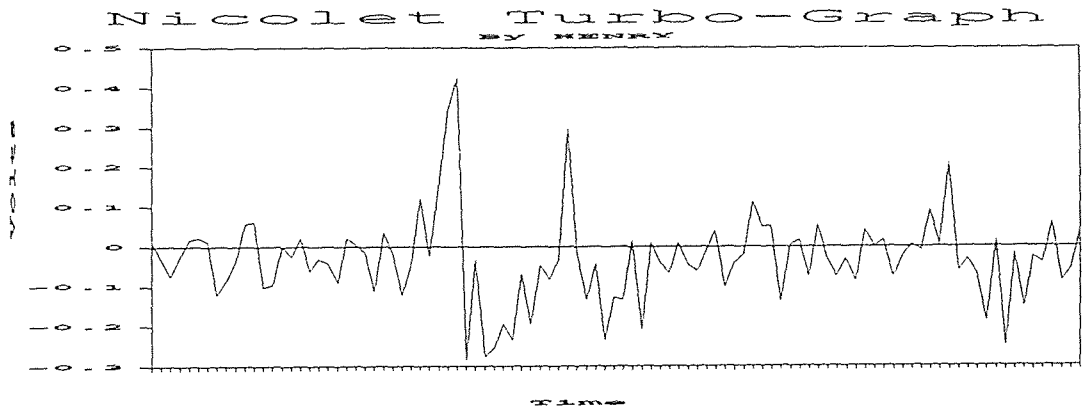
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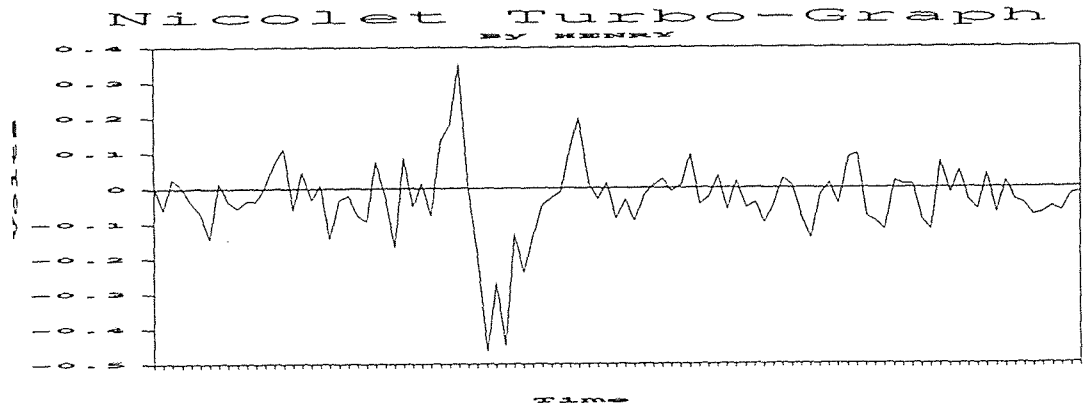
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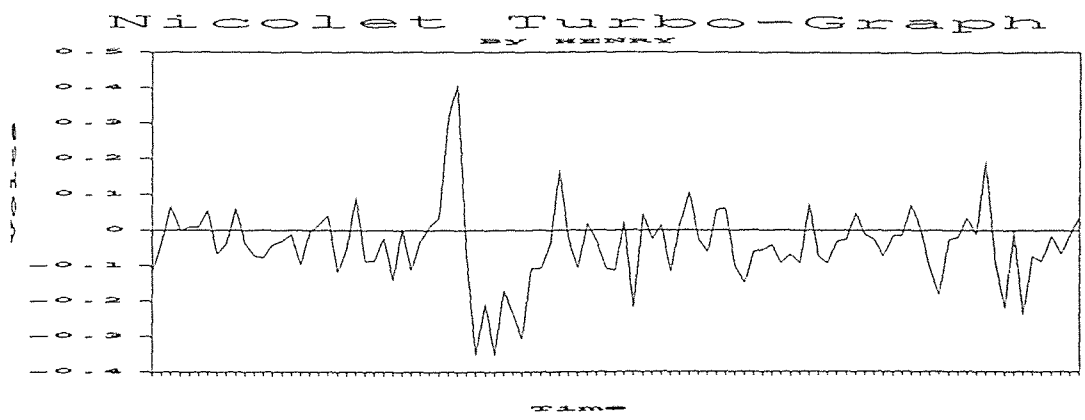
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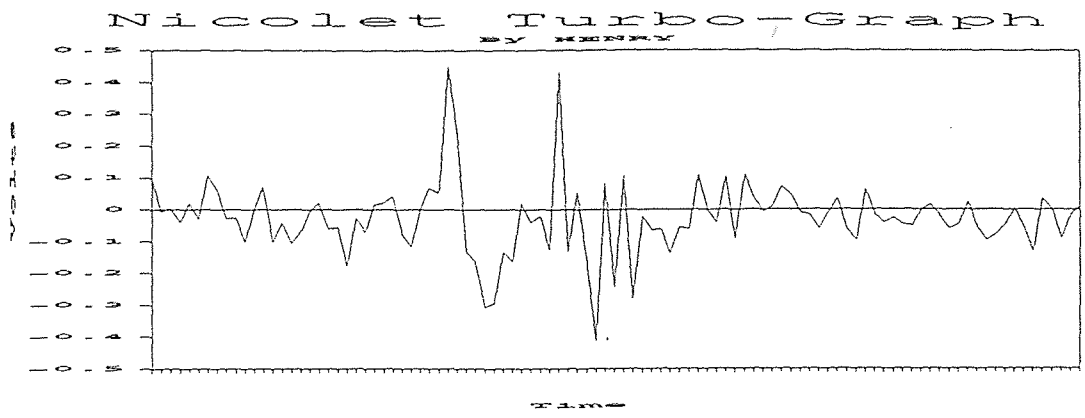
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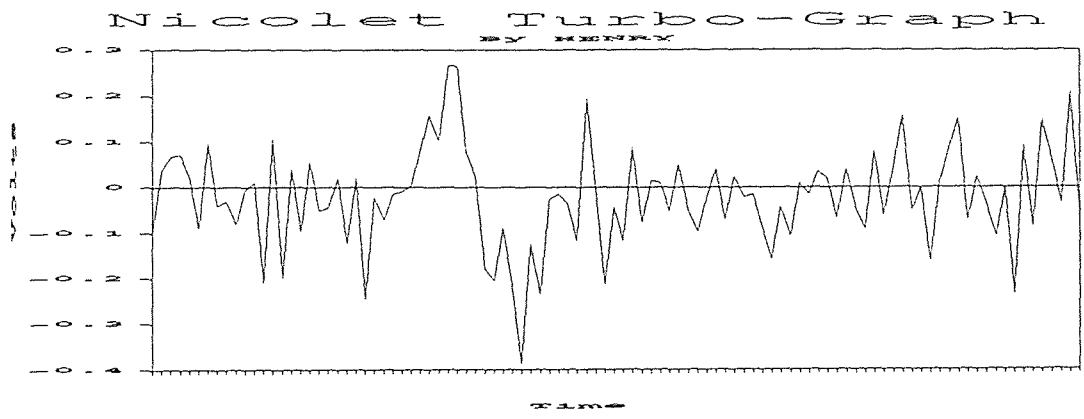
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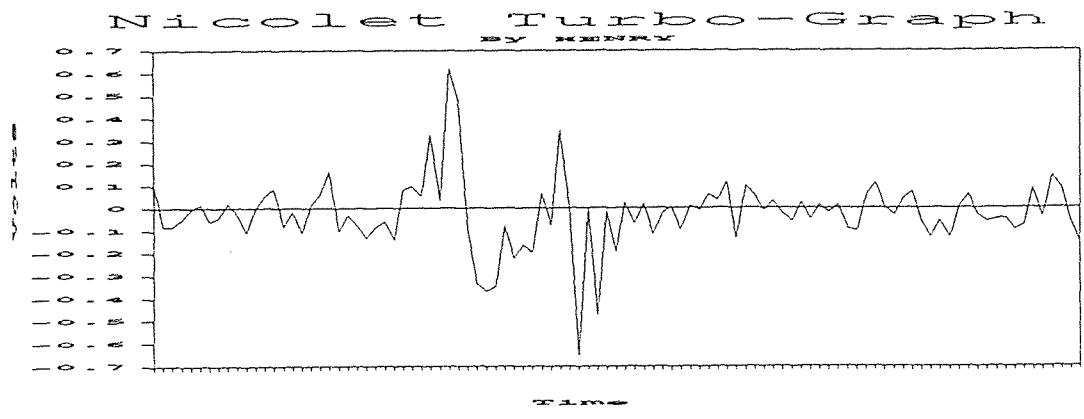
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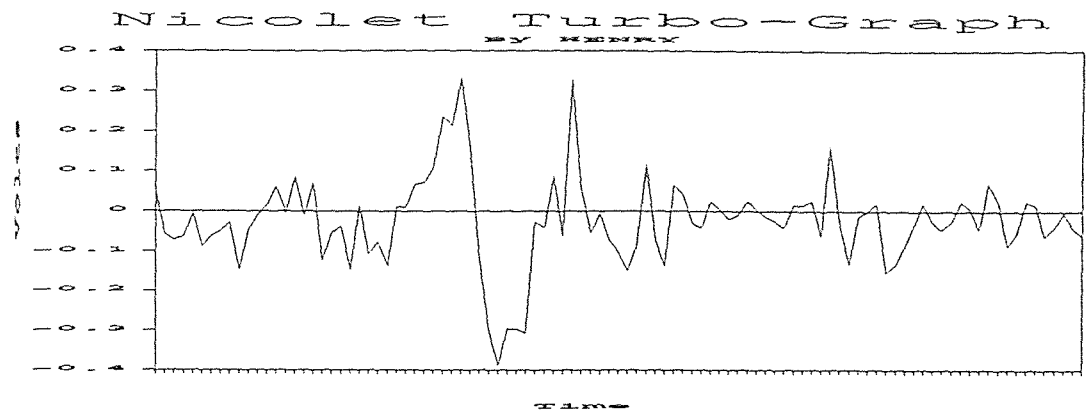
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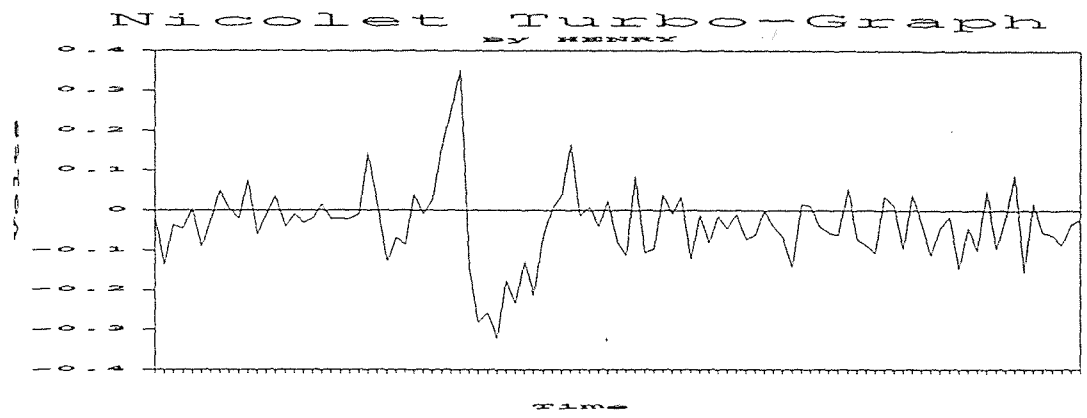
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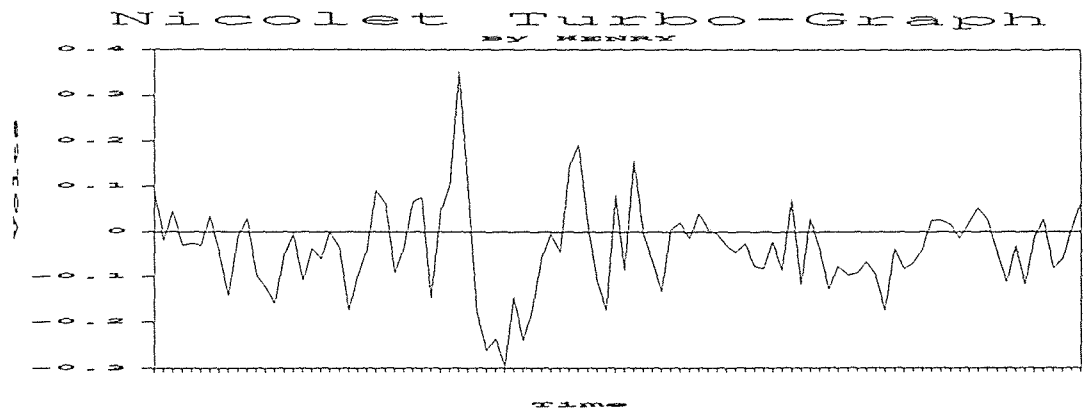
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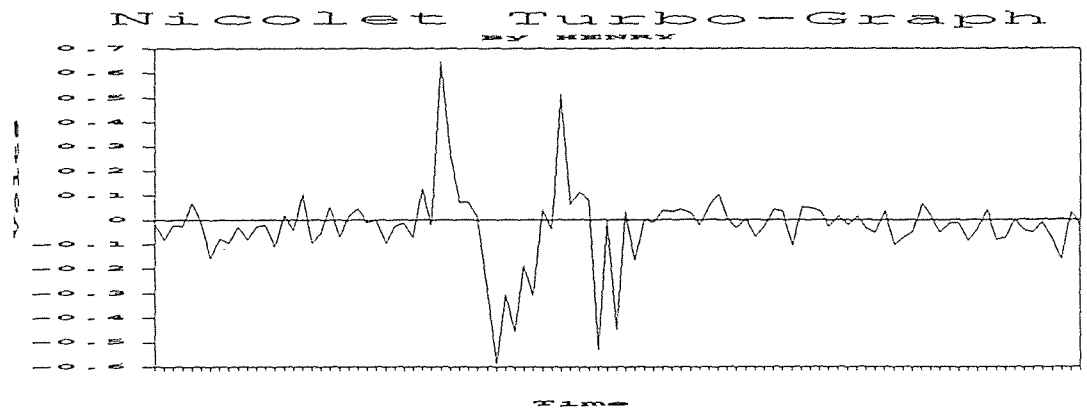
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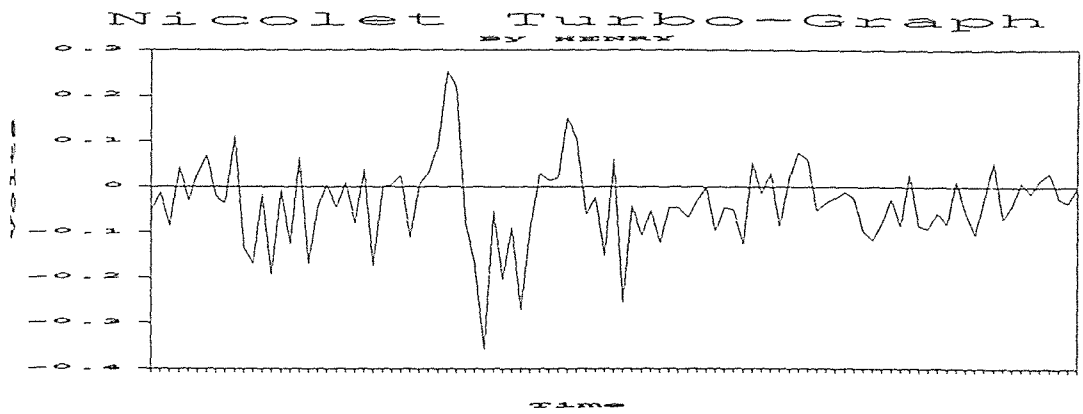
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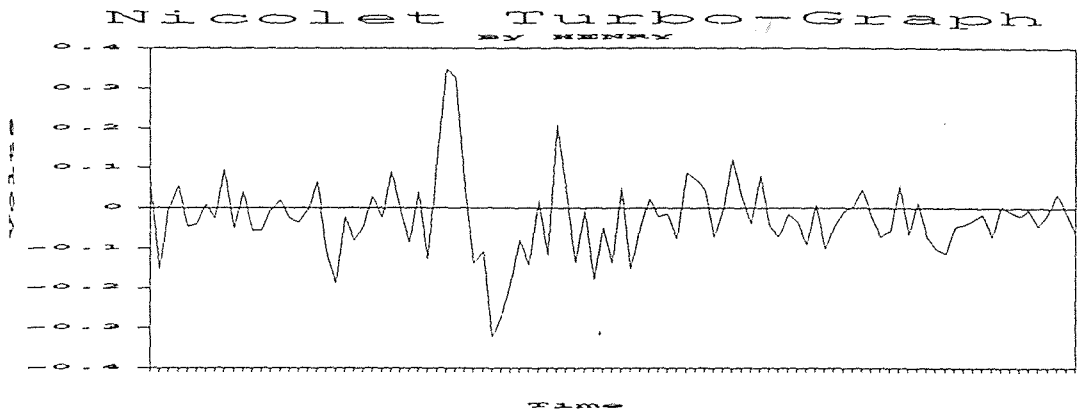
by Henry
Volts
Time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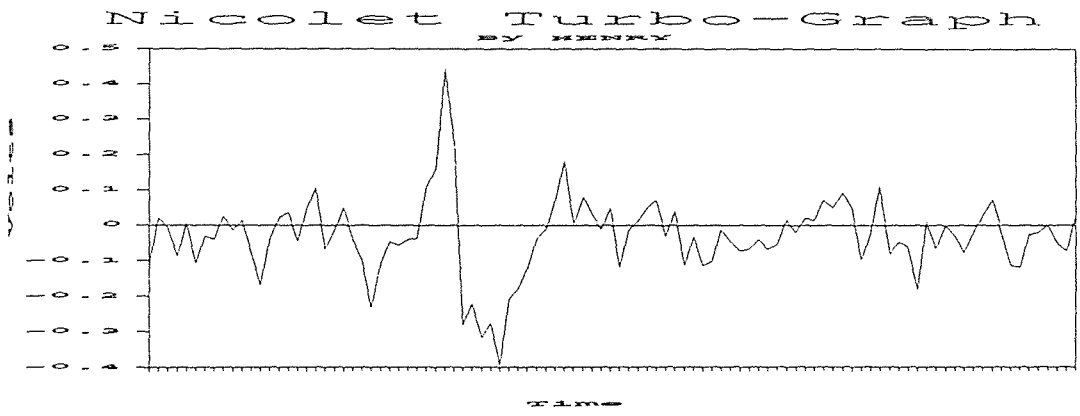
Volts
Time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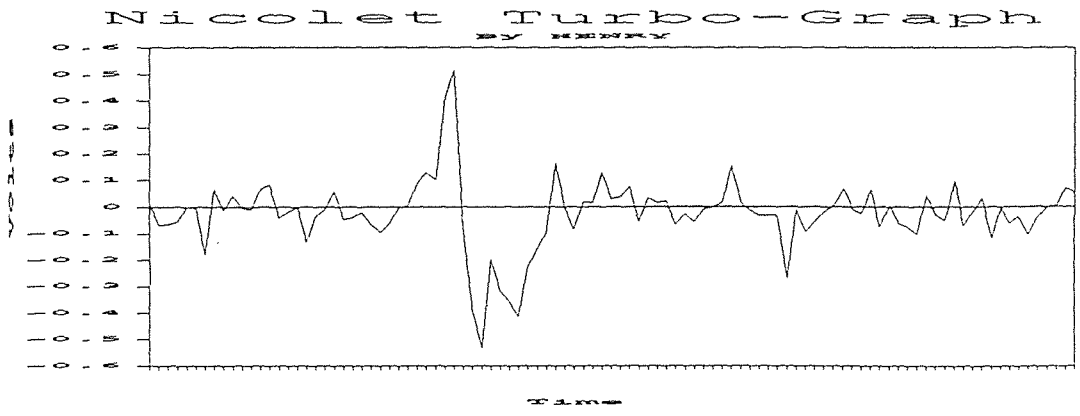
Volts
Time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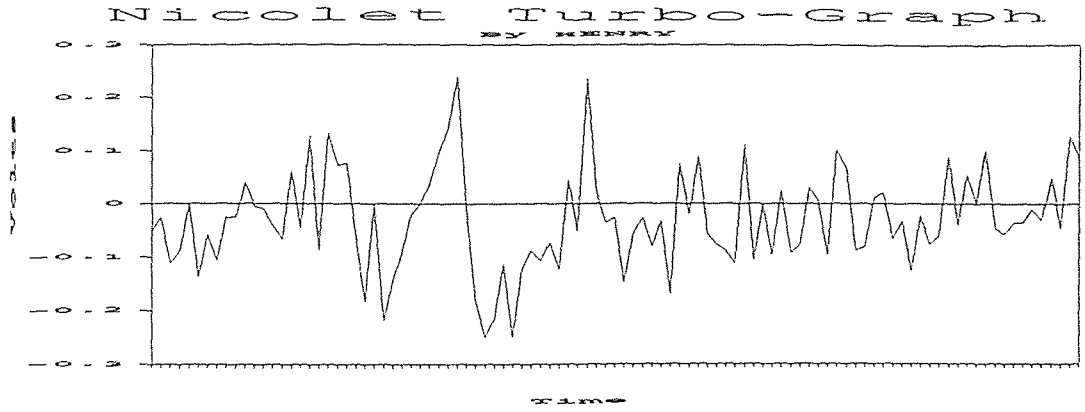
Volts
Time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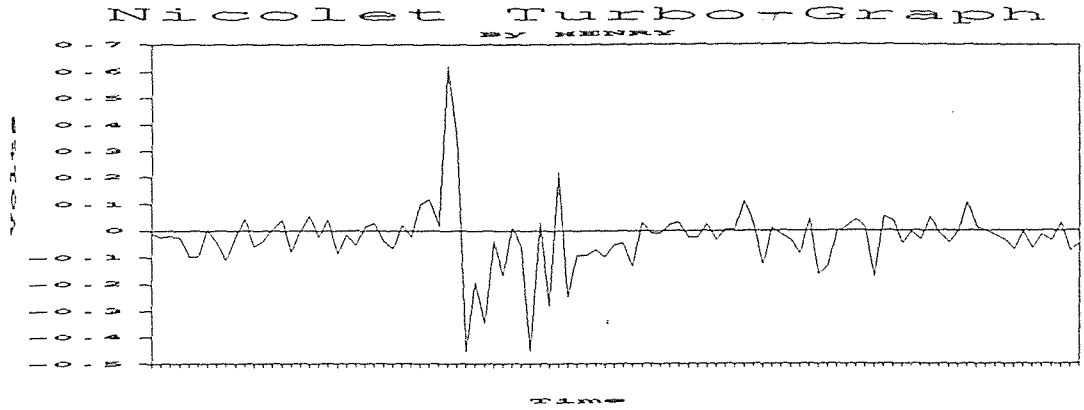
volts
time

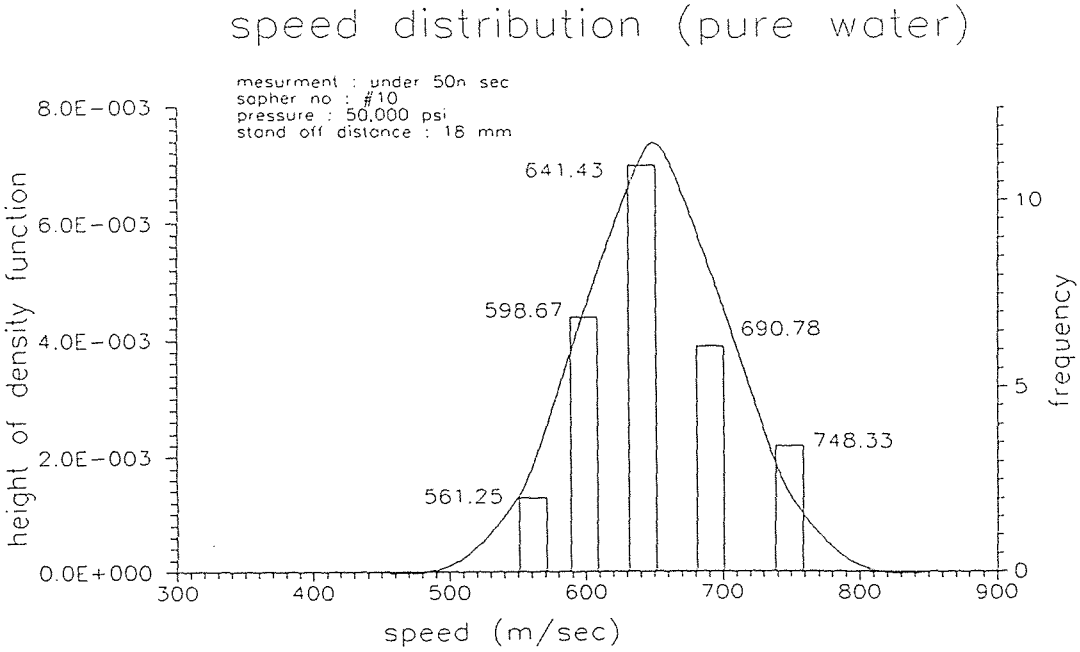

Nicolet Turbo-Graph
by HENRY
volts
time

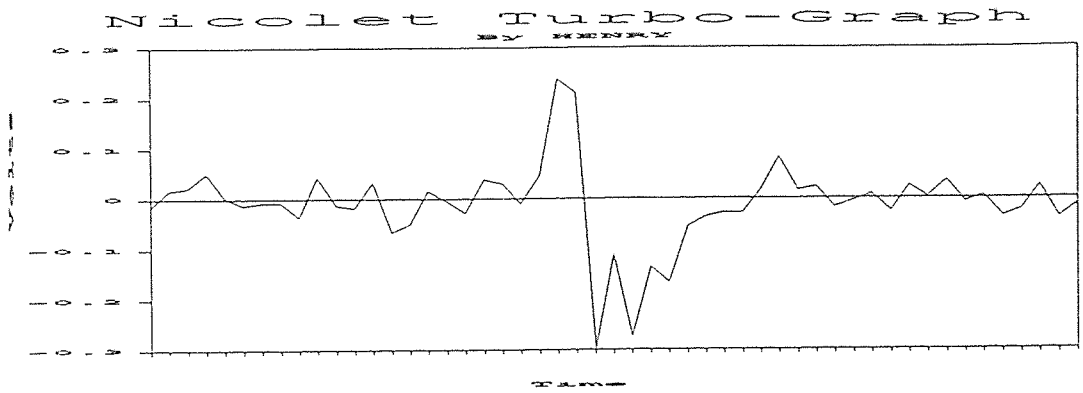
WATER JET VELOCITIES MESUREMENT

(PURE WATER)

Pressure : 50,000 Psi
Stand Off Distance : 18 mm
Data : 30 Set
Time Base : 50n Sec

STATISTICS ANALYSIS
Sample Size : 30
Minimum = 561.25
maximum = 748.33
Range = 187.08
Median = 641.43
Arithmetic Mean = 650.2288
Geometric Mean = 648.1198
Variance = 2884.551
Standard Deviation = 53.70802
Coefficient of Variation = 8.259864 %
Skewness : Bata (1) = 0.1605944 (+)
Kurtosis : Beta (2) = 2.327333




Nicolet Turbo-Graph
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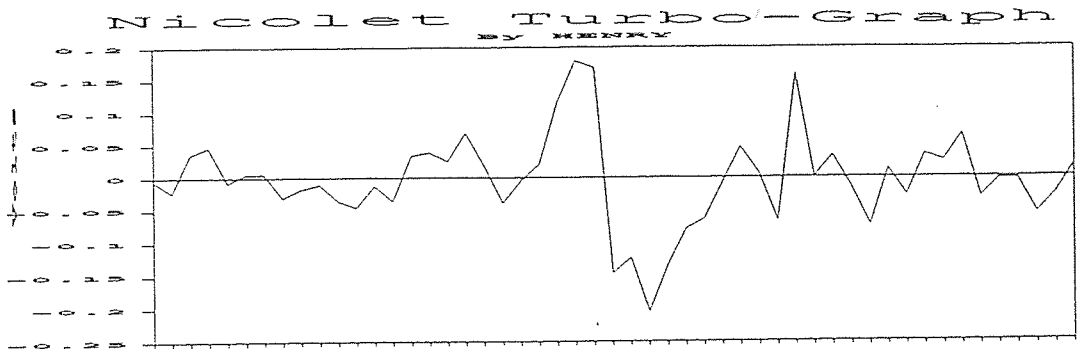
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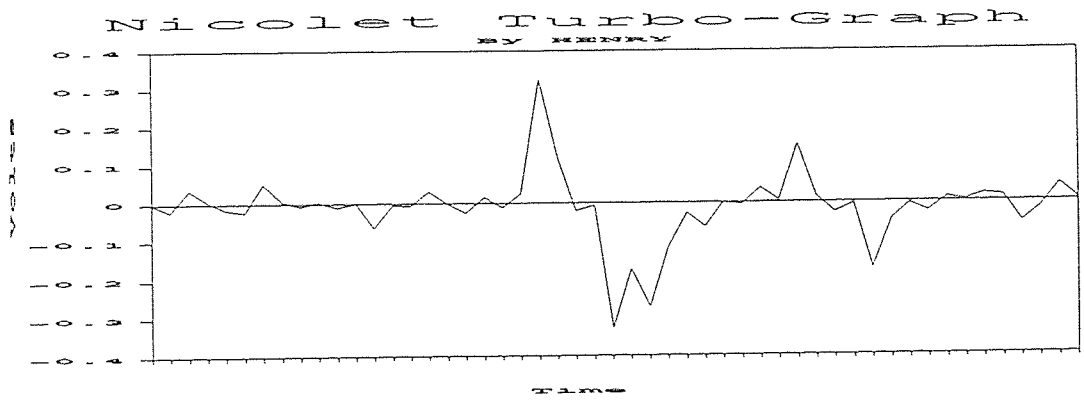
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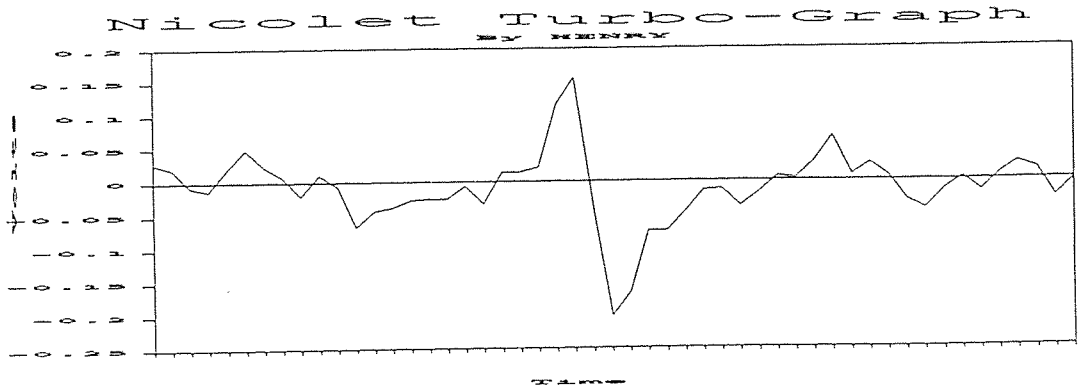
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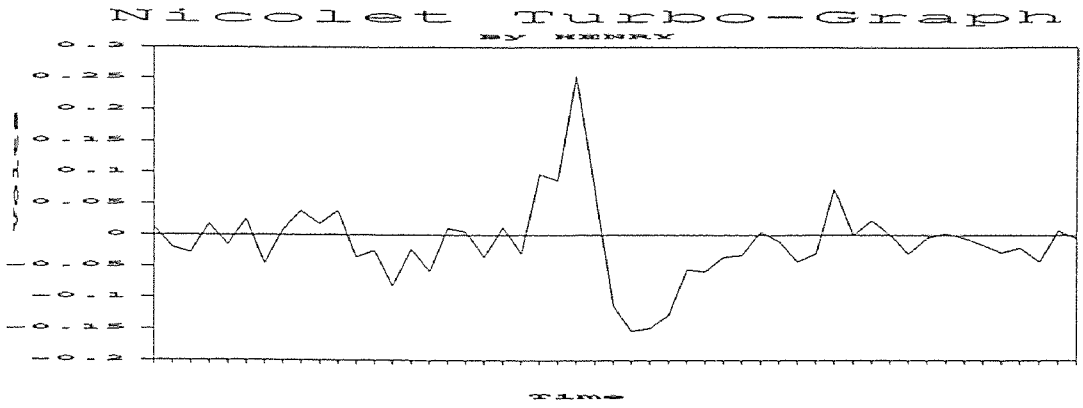
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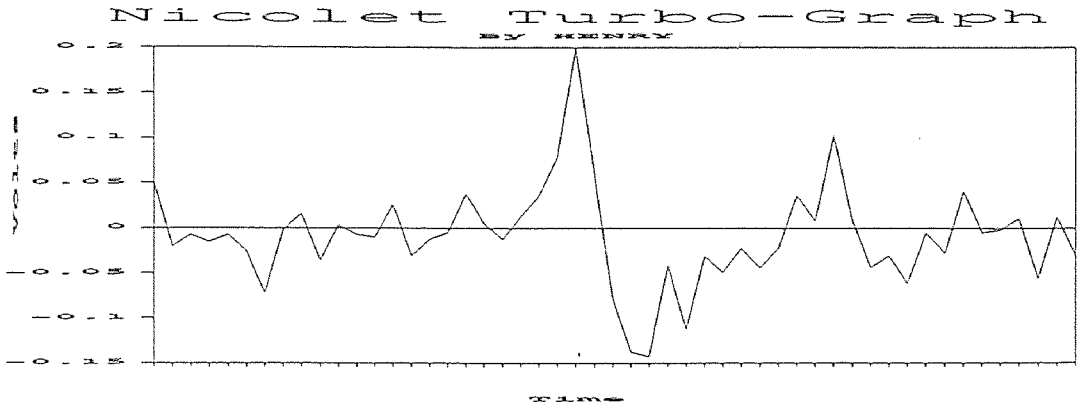
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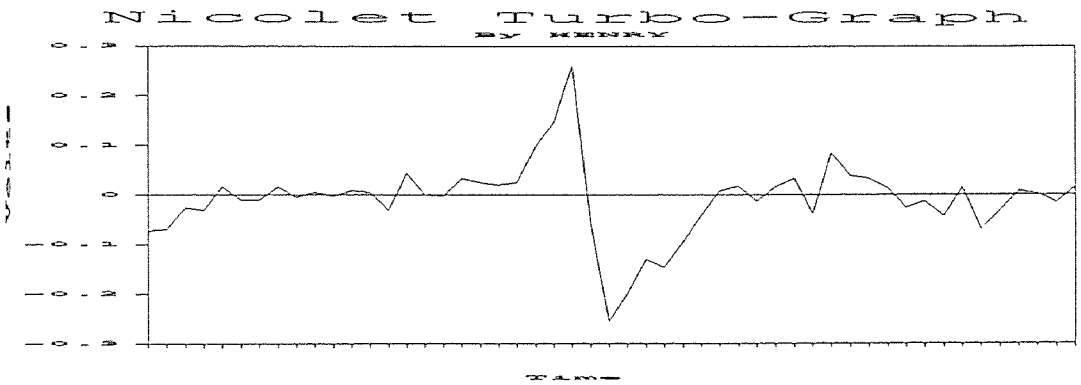
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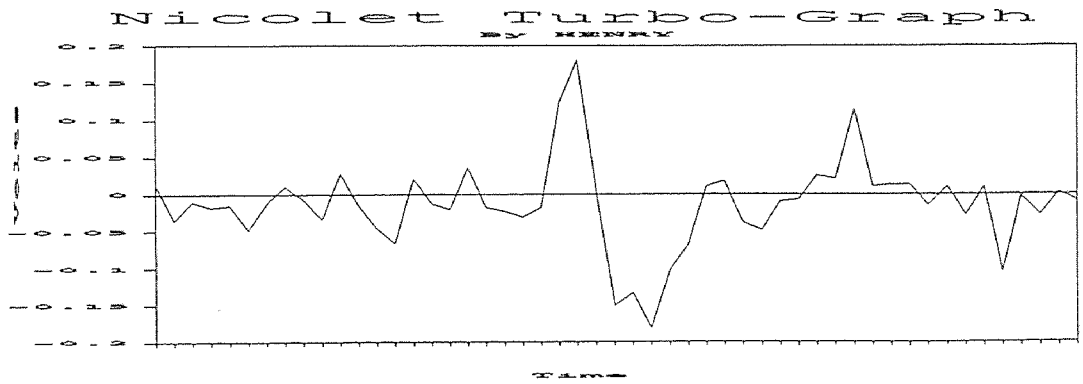
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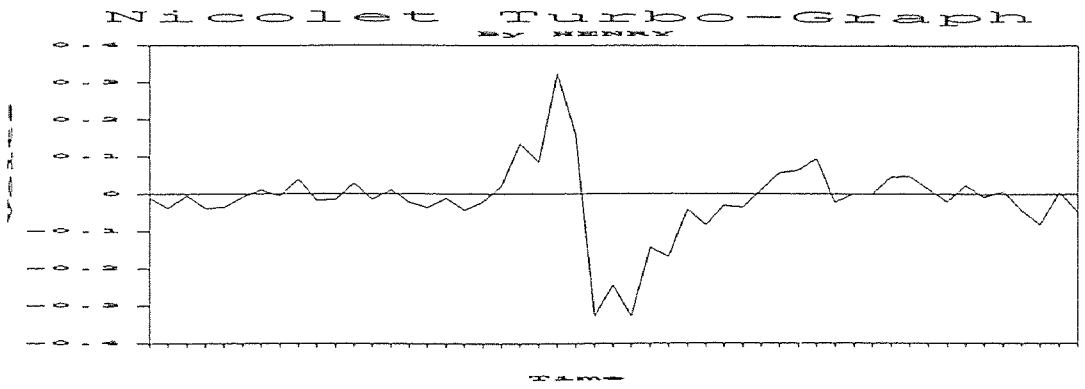
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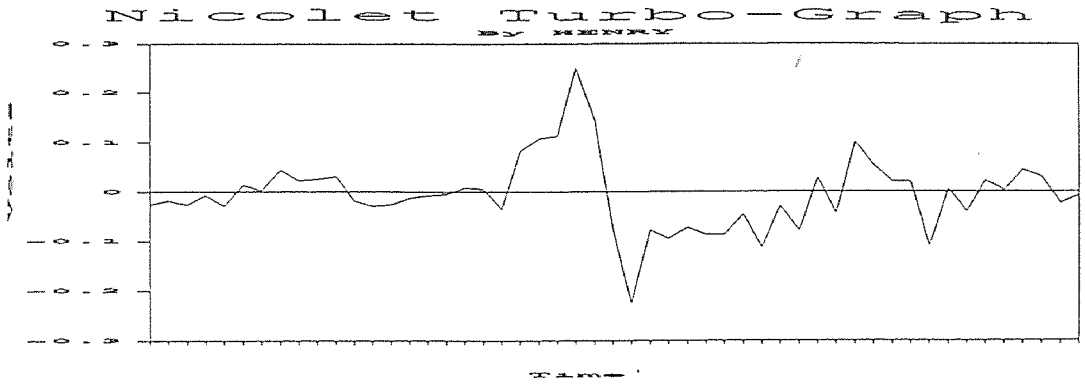
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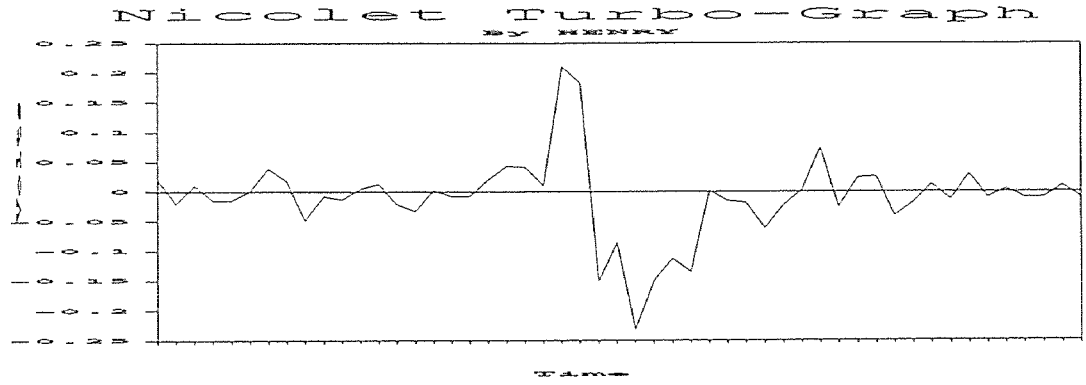
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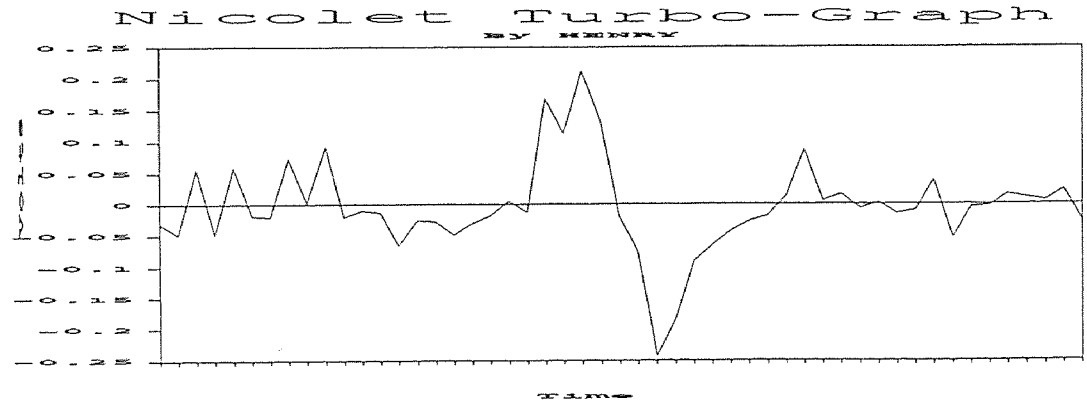
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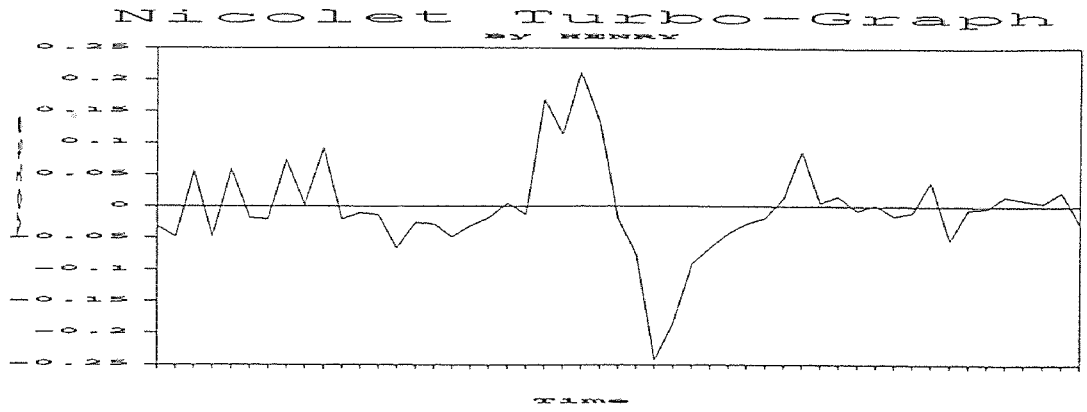
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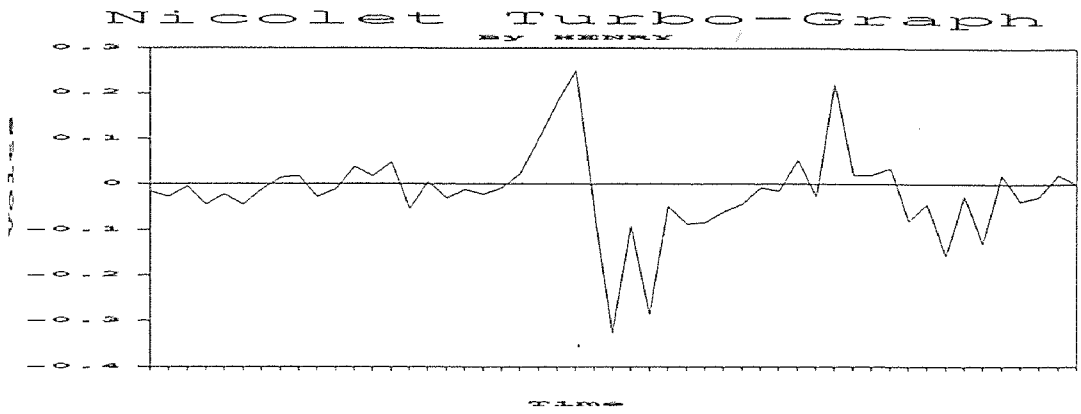
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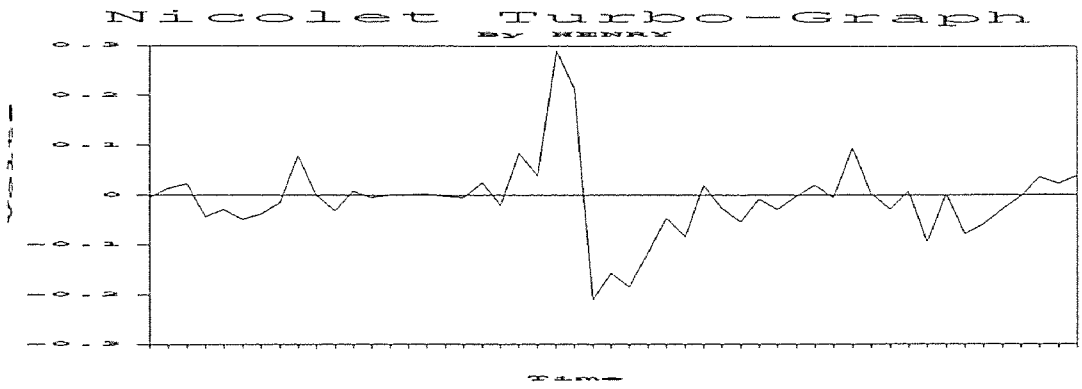
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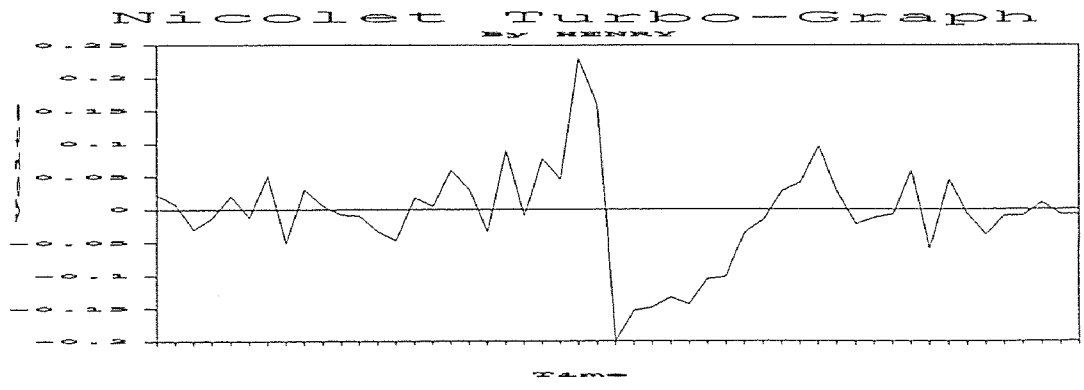
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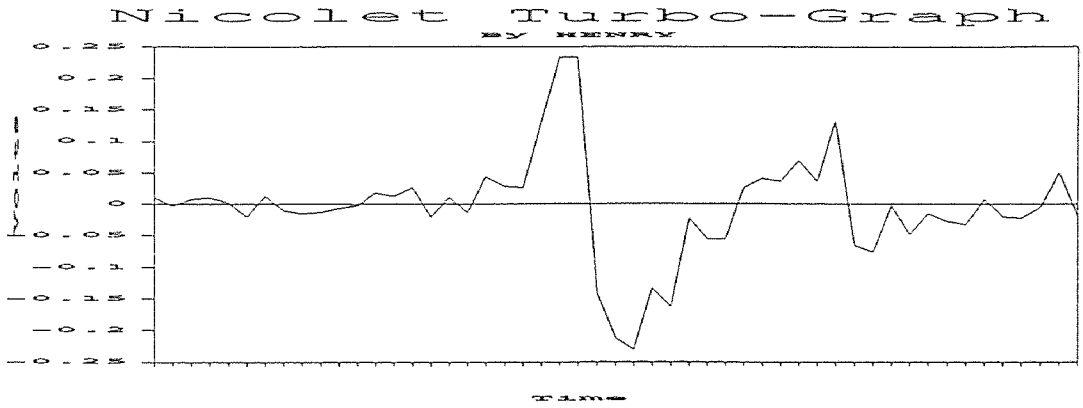
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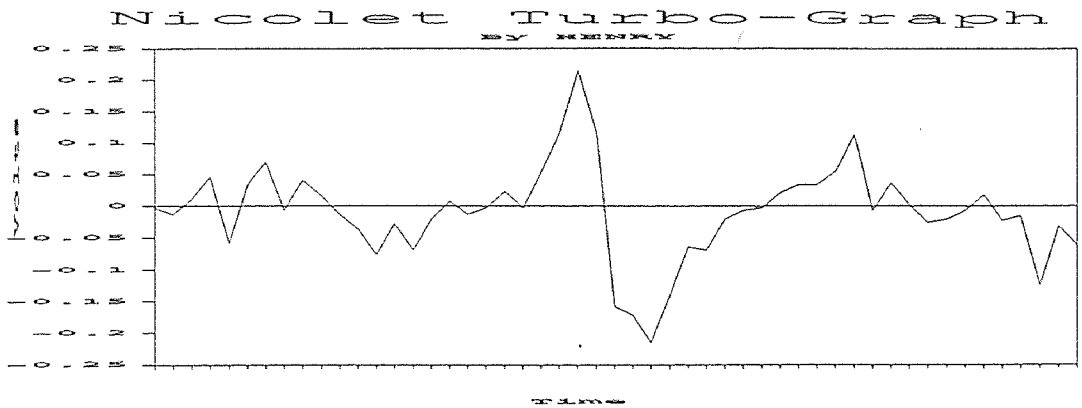
by HENRY
volts
time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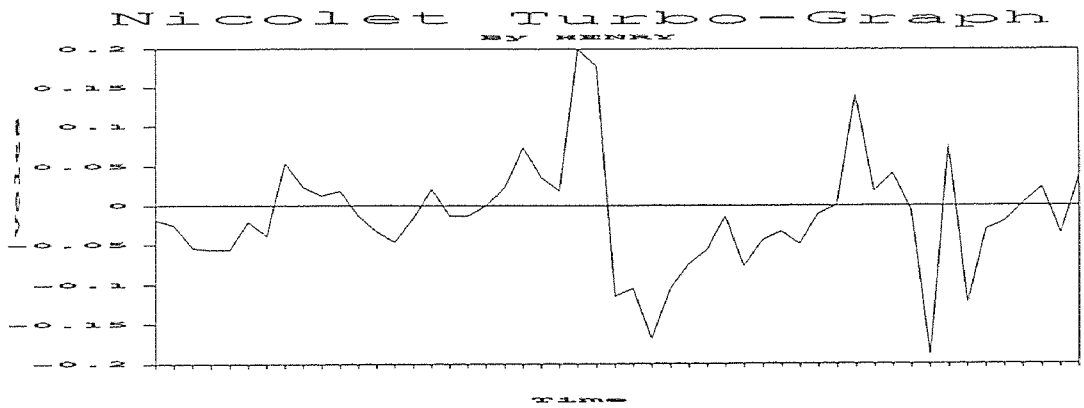
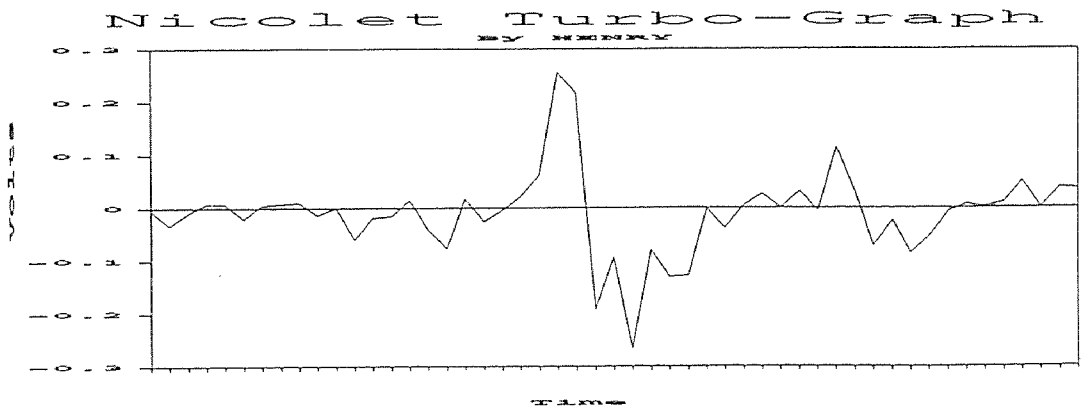
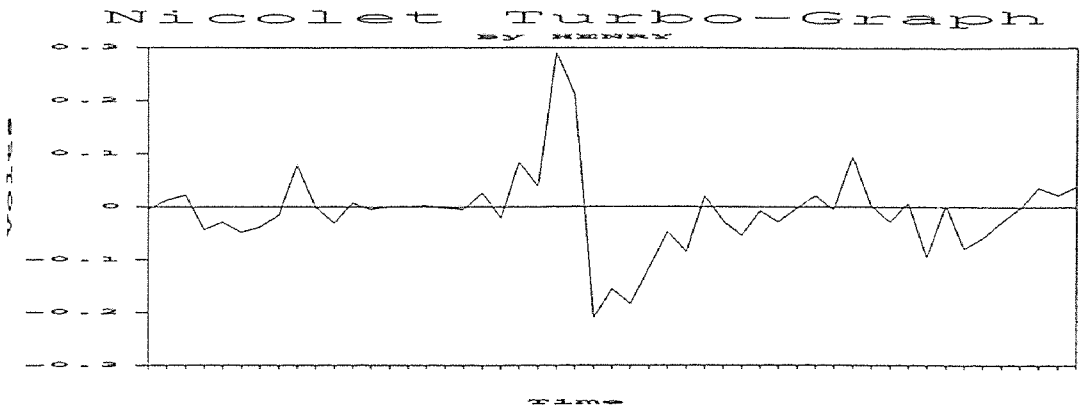
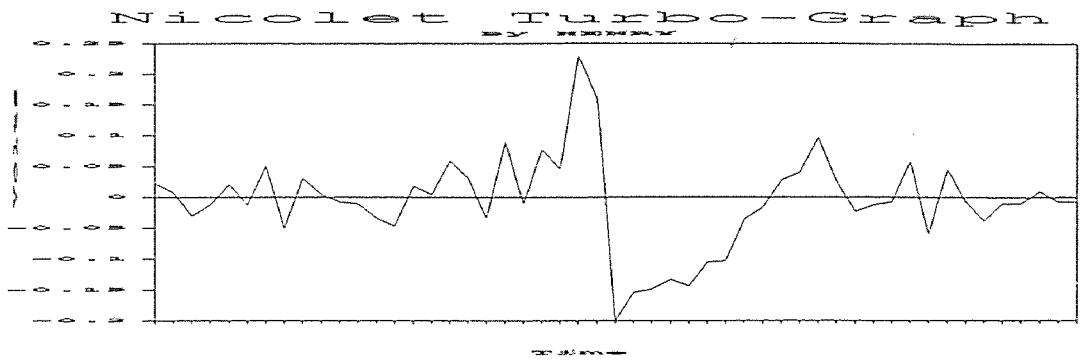
volts
time


Nicolet Turbo-Graph
by HENRY
volts
time


Nicolet Turbo-Graph
by HENRY
volts
time


Nicolet Turbo-Graph
by HENRY
time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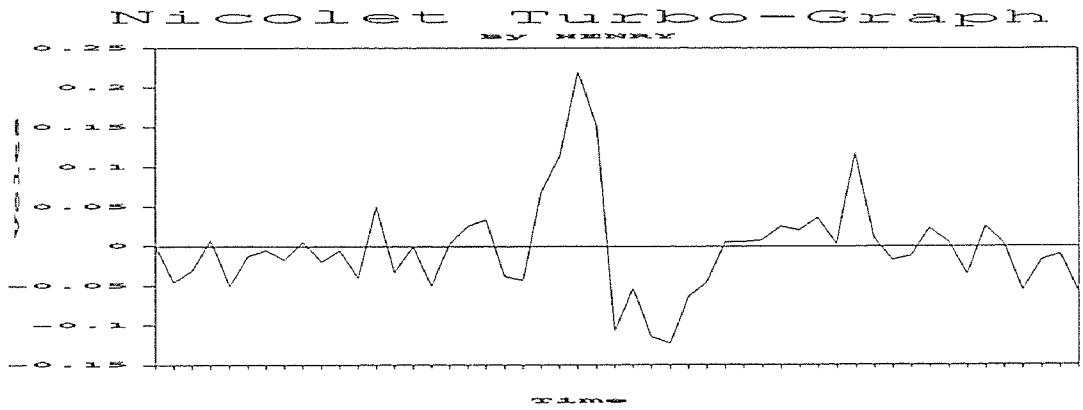
Nicolet Turbo-Graph
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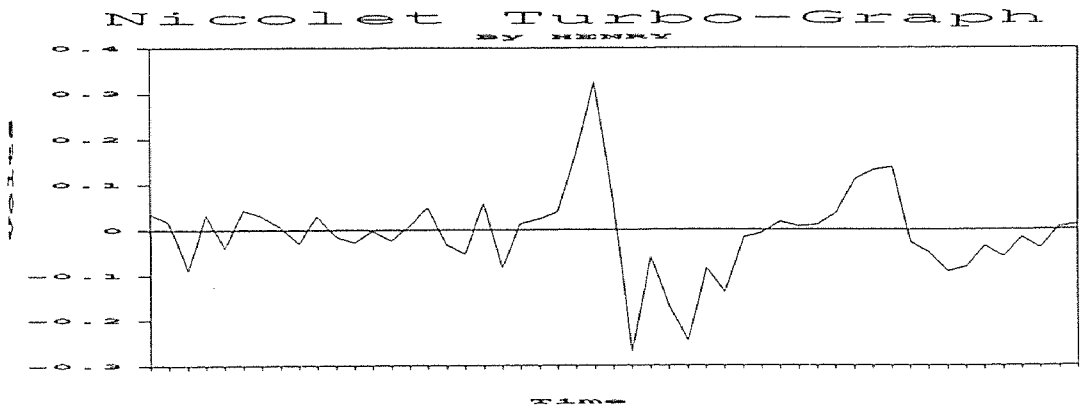
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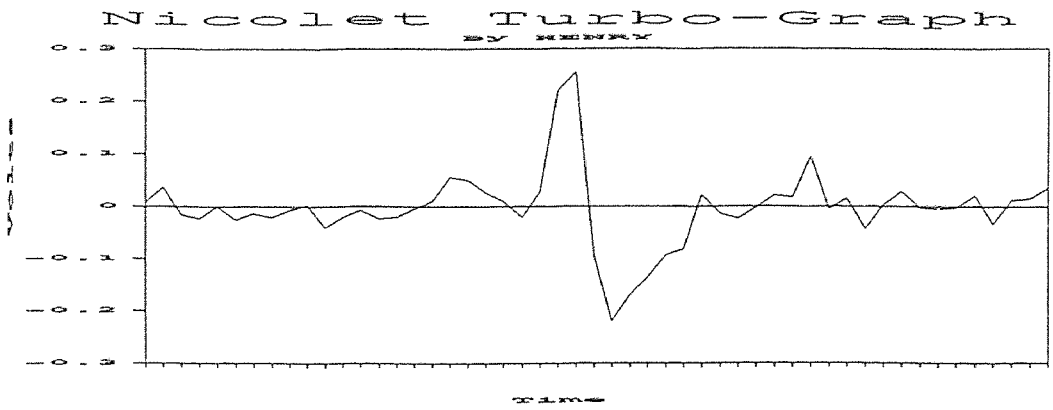
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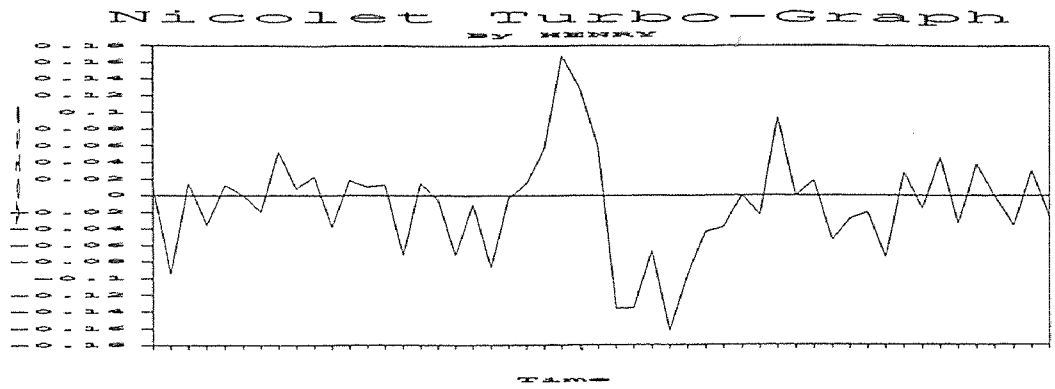
Time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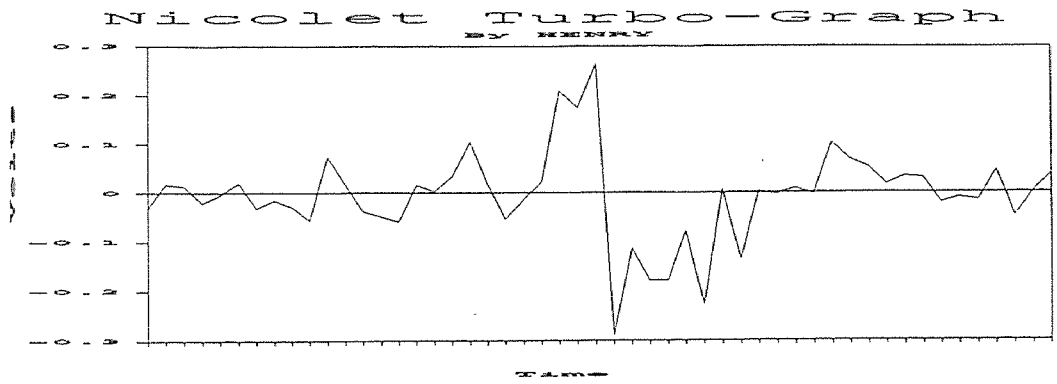
Time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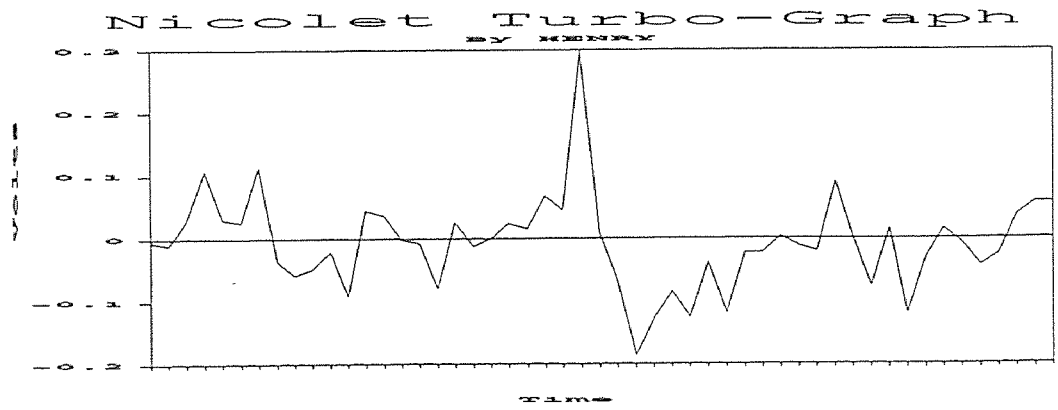
Time


Nicolet Turbo-Graph
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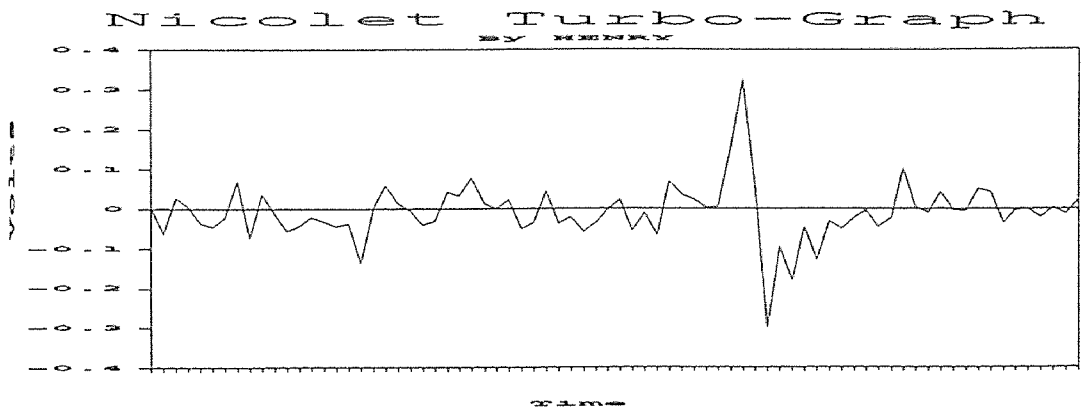
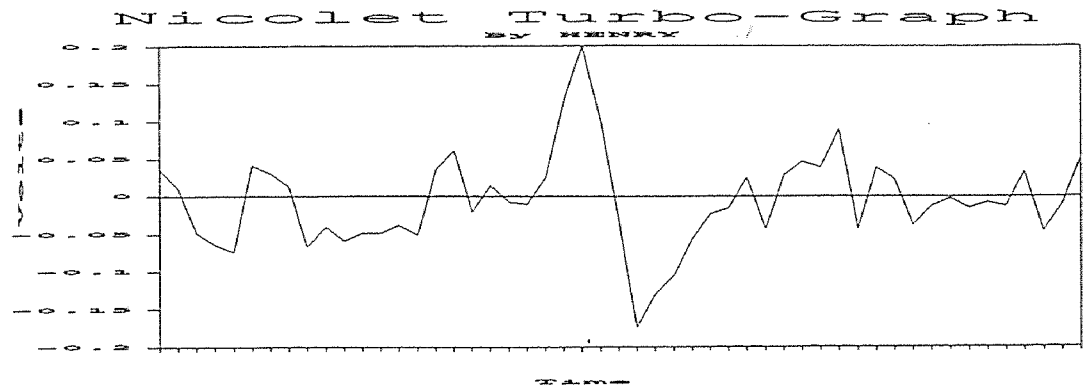
Time


Nicolet Turbo-Graph
by HENRY
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
Volts
time

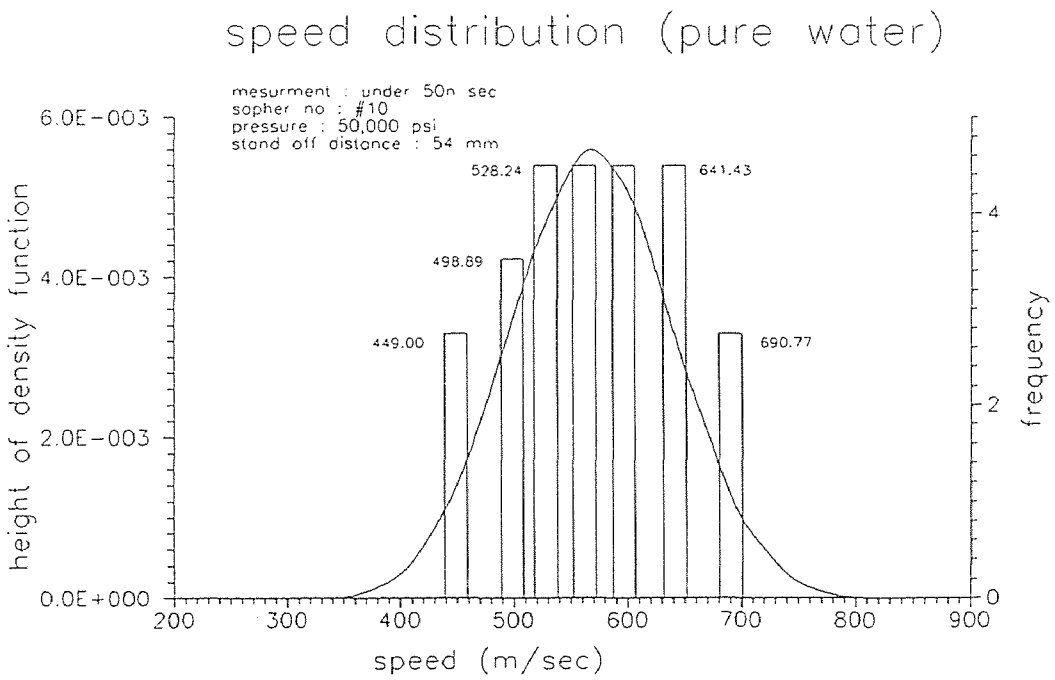

Nicolet Turbo-Graph
by HENRY
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
Volts
time

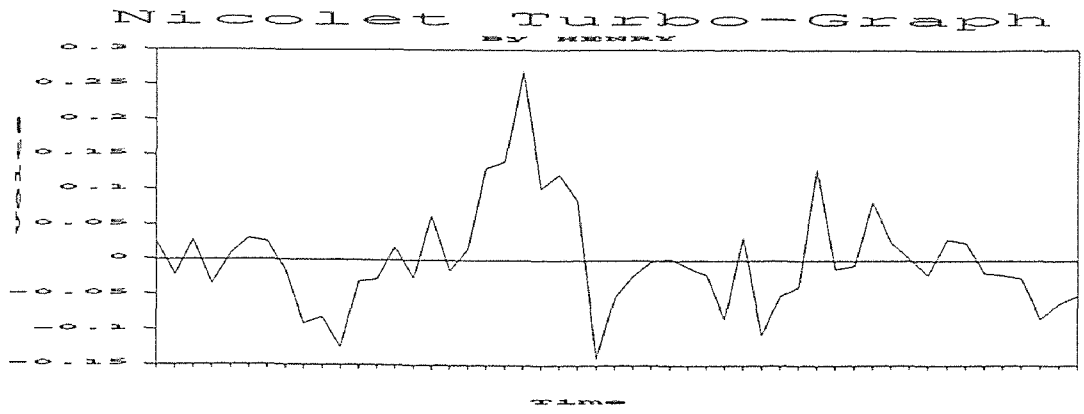
WATER JET VELOCITIES MESUREMENT

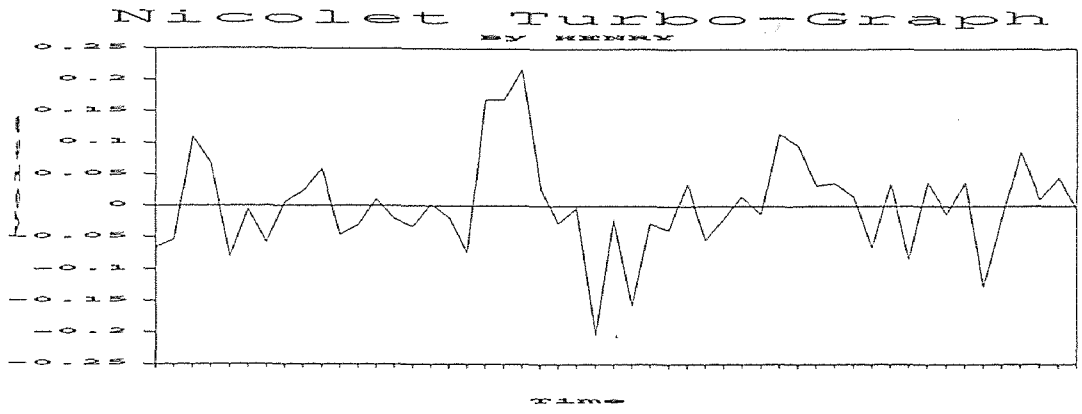
(PURE WATER)

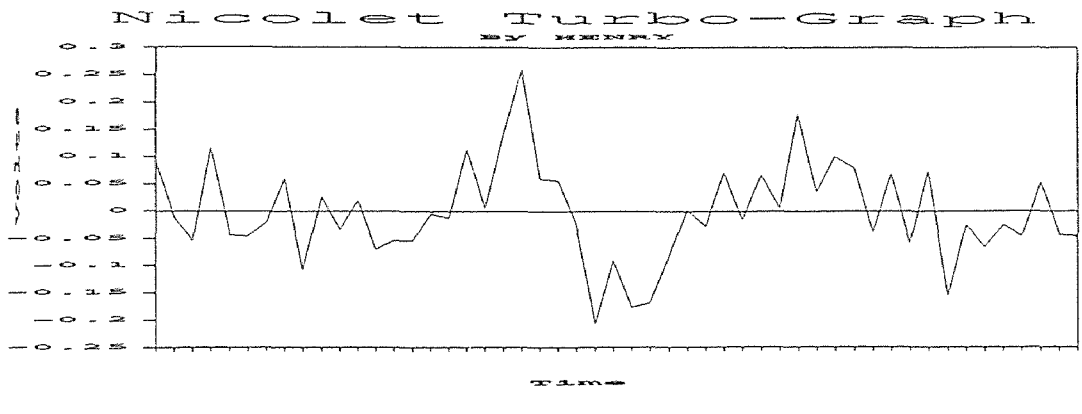
Pressure : 50,000 Psi
Stand Off Distance : 54 mm
Data : 30 Set
Time Base : 50n Sec

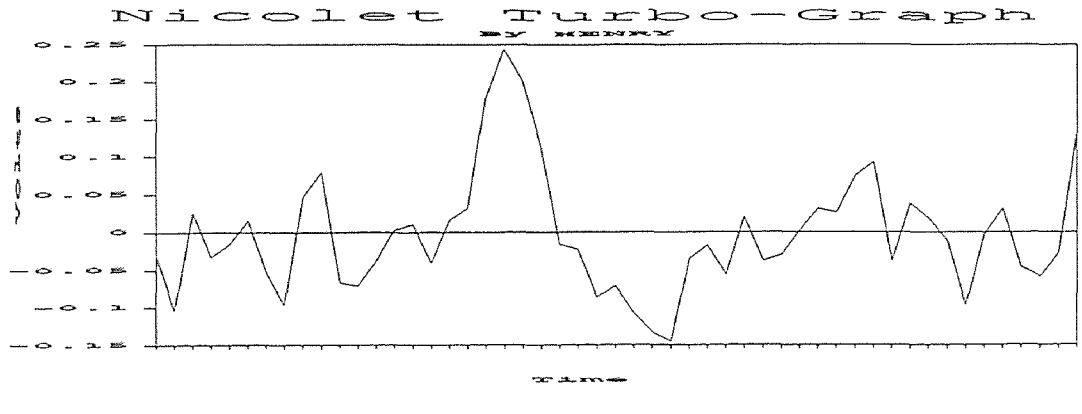
STATISTICS ANALYSIS
Sample Size : 30
Minimum = 499
maximum = 690.77
Range = 241.77
Median = 561.25
Arithmetic Mean = 568.8406
Geometric Mean = 564.5195
Variance = 5047.923
Standard Deviation = 71.04874
Coefficient of Variation = 12.4901 %
Skewness : Bata (1) = 3.618758E-03 (+)
Kurtosis : Beta (2) = 2.075027

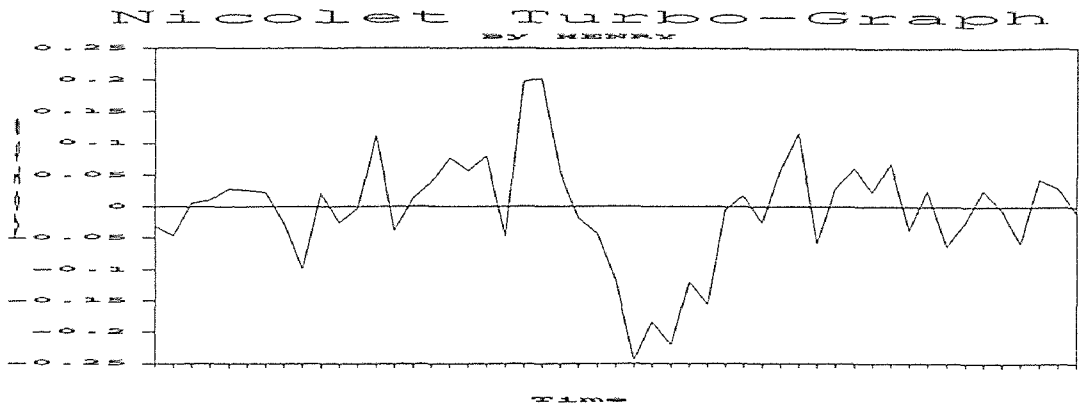



Nicolet Turbo-Graph
by Henry
Value
time


Nicolet Turbo-Graph
by Henry
Value
time


Nicolet Turbo-Graph
by Henry
Value
time


Nicolet Turbo-Graph
by Henry
Value
time


Nicolet Turbo-Graph
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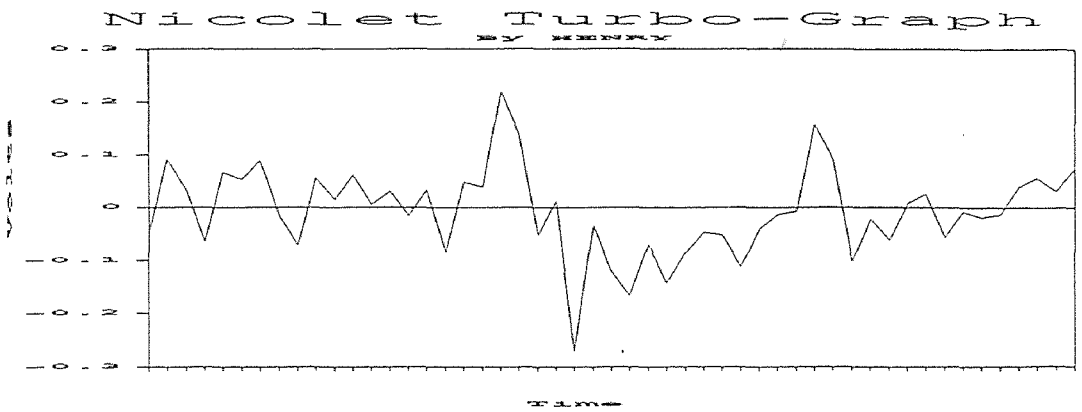
time


Nicolet Turbo-Graph
by HENRY
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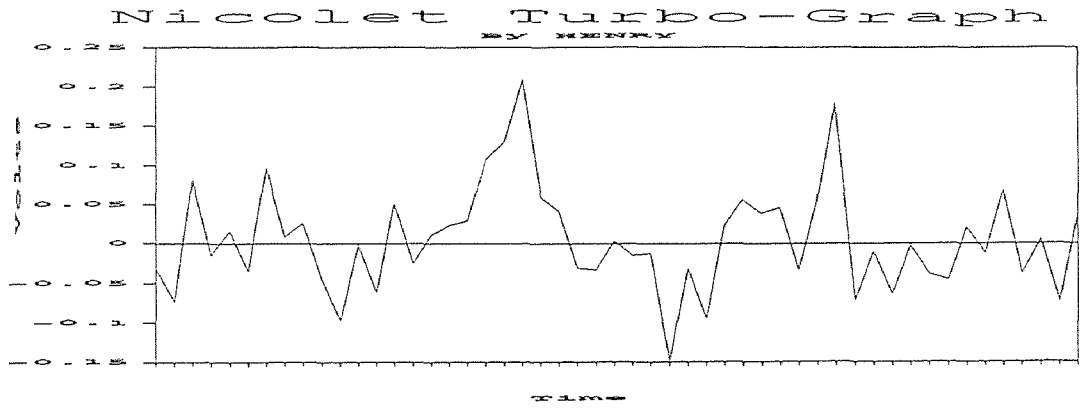
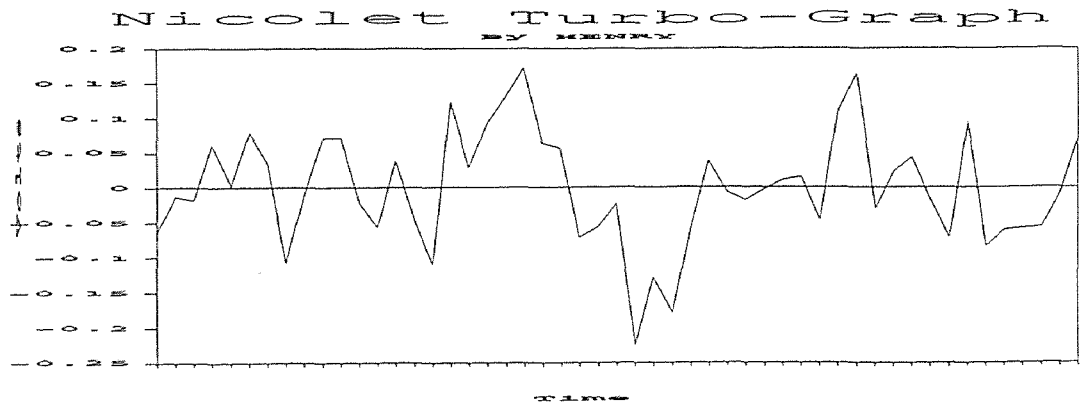
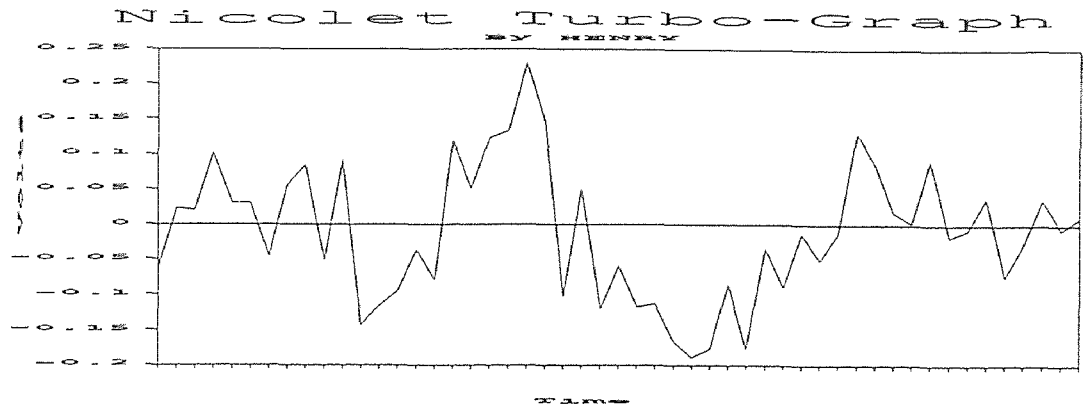
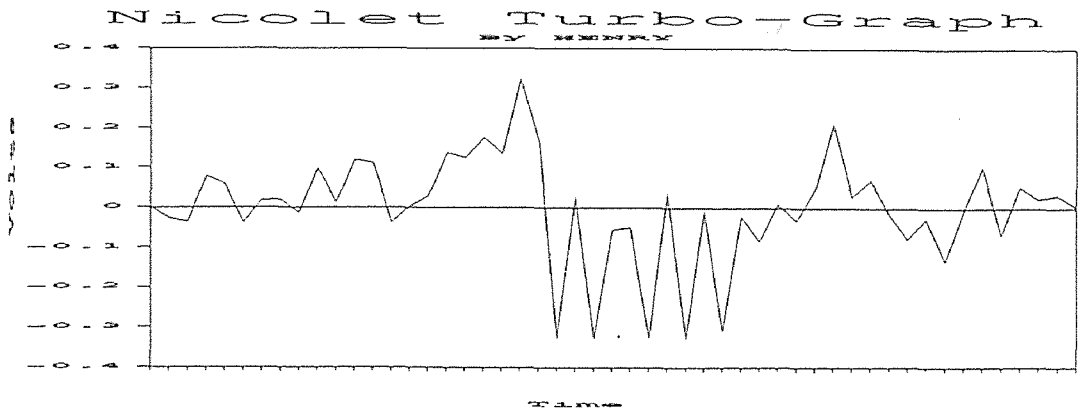
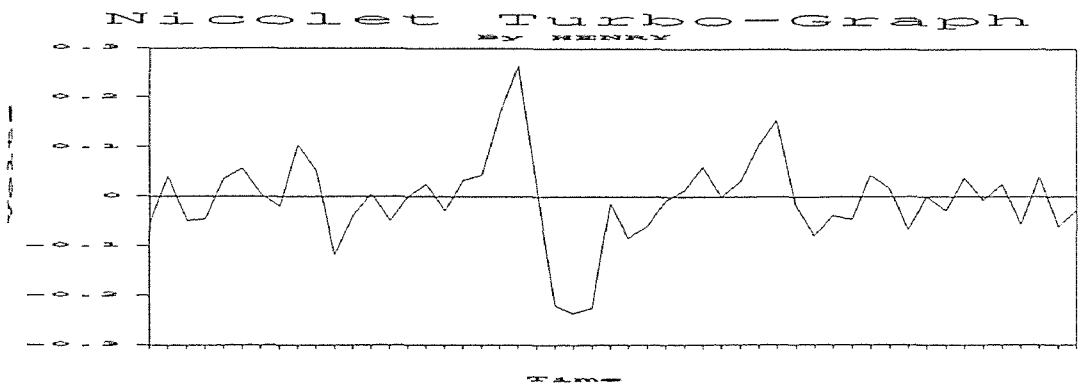

Nicolet Turbo-Graph
by HENRY
time


Nicolet Turbo-Graph
by HENRY
time


Nicolet Turbo-Graph
by HENRY
Volts
time


Nicolet Turbo-Graph
by HENRY
Volts
time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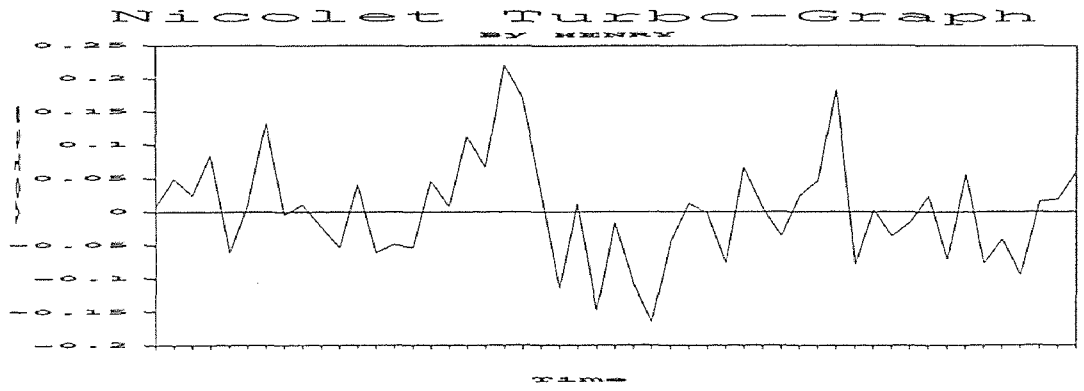
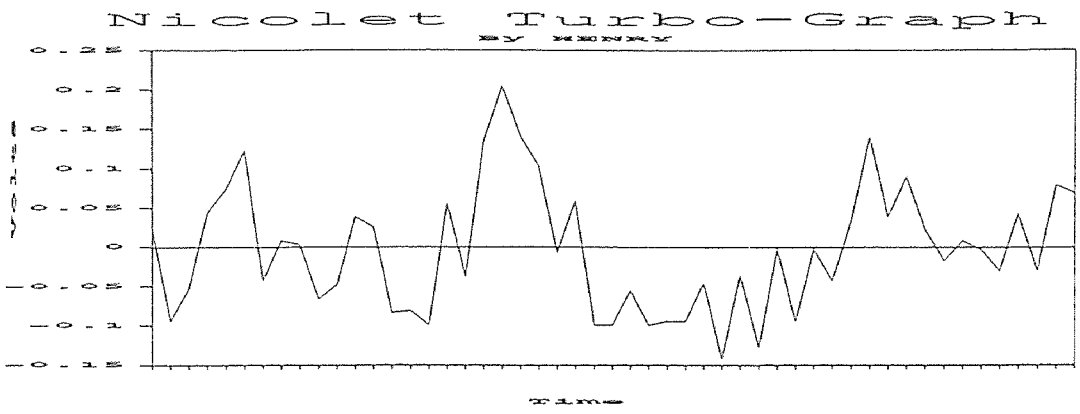
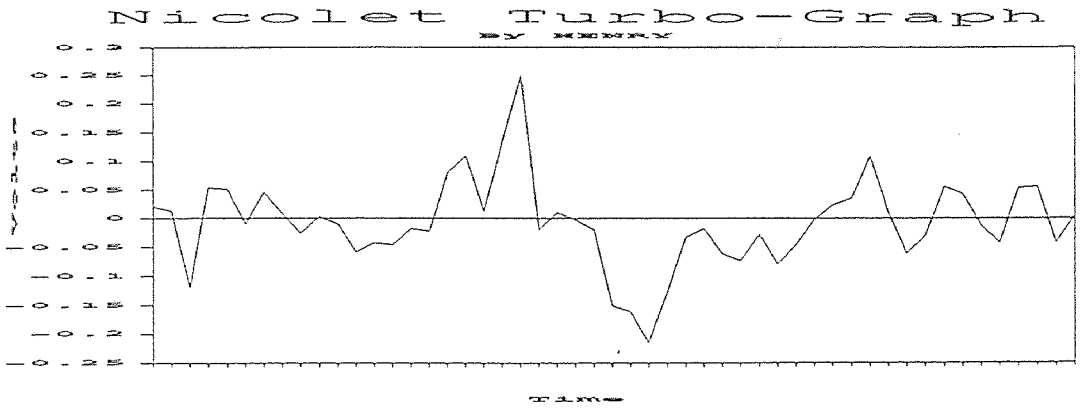
by HENRY
Volts
time


Nicolet Turbo-Graph
by HENRY
Volts
time


Nicolet Turbo-Graph
by HENRY
time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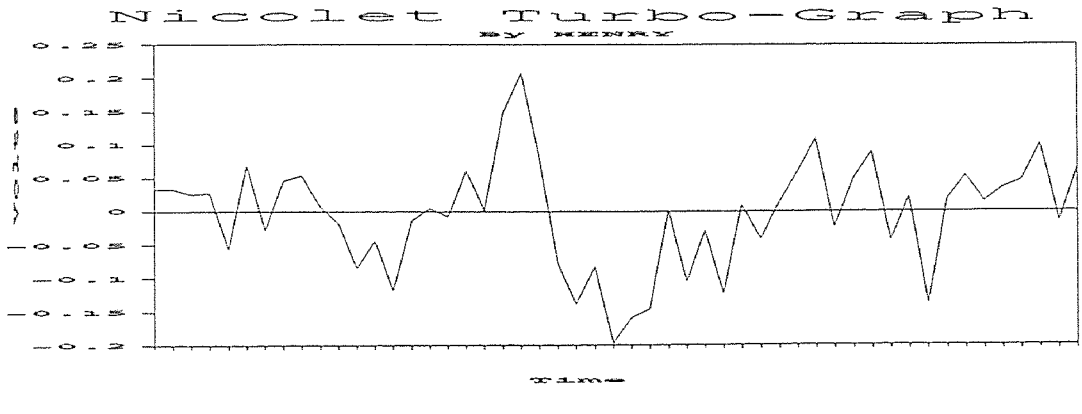
by HENRY
time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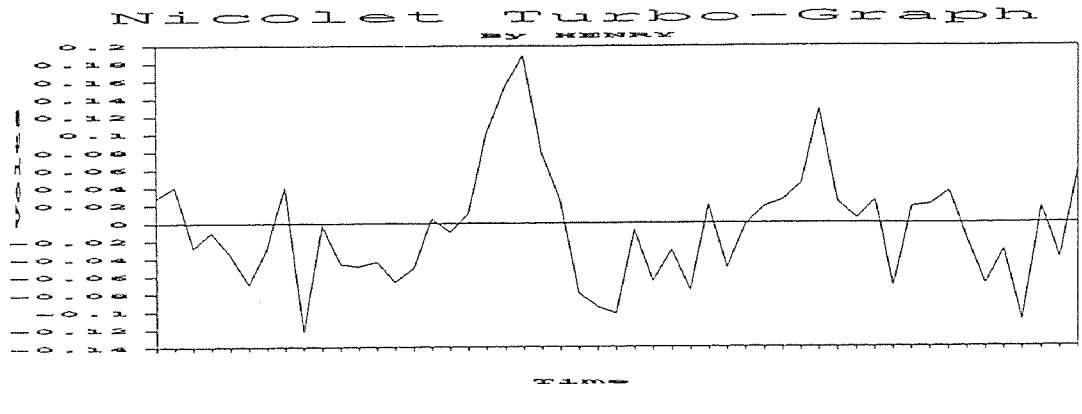
by HENRY
time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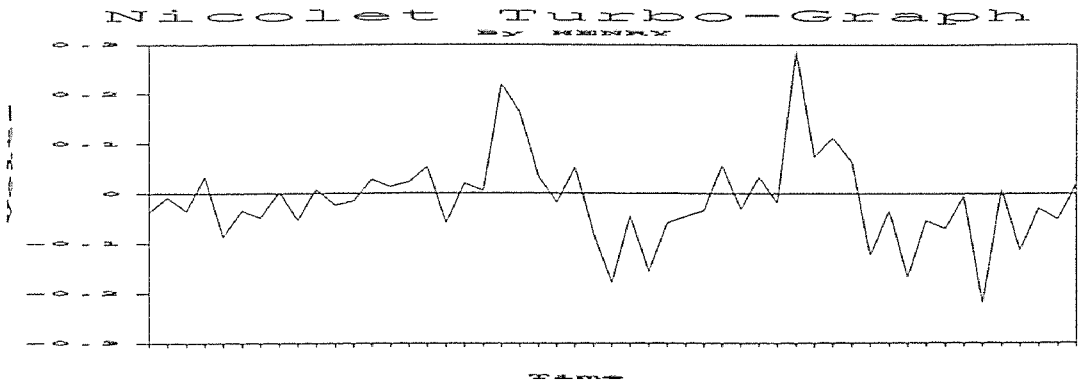
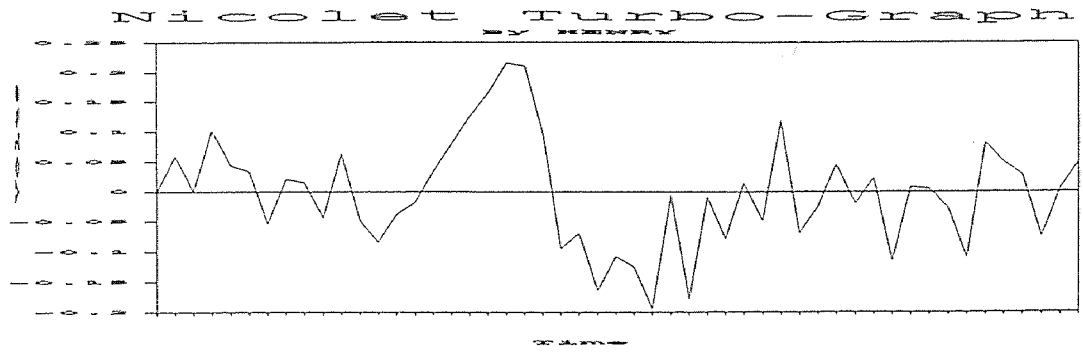
by HENRY
time


Nicolet Turbo-Graph
by HENRY
time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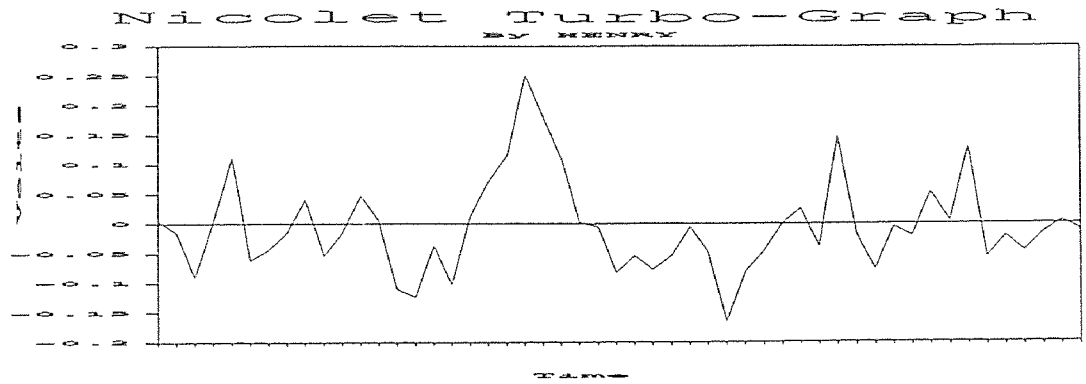
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by HENRY
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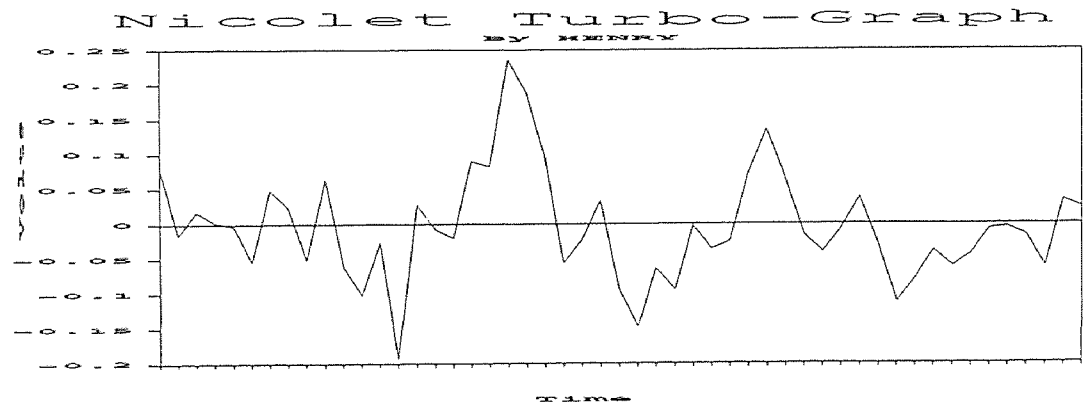
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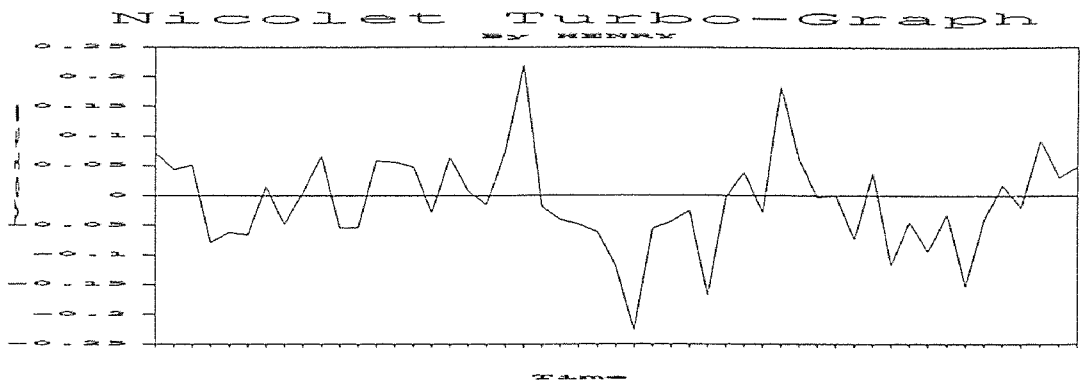
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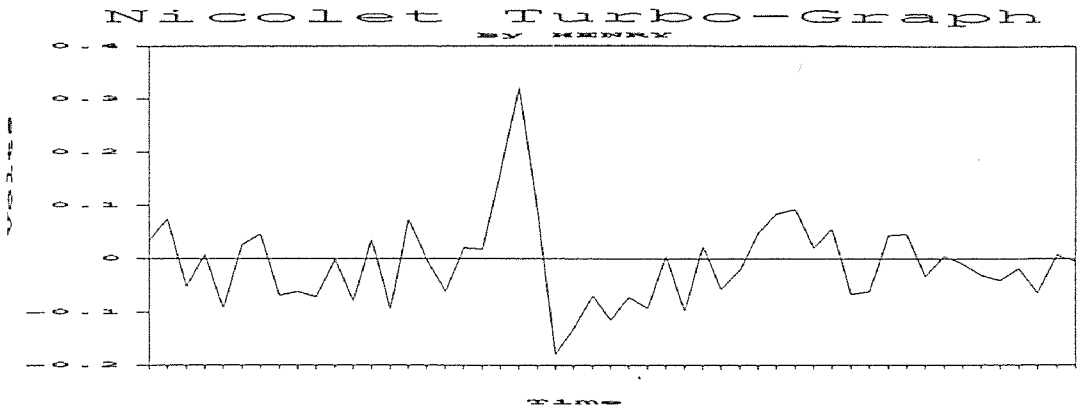
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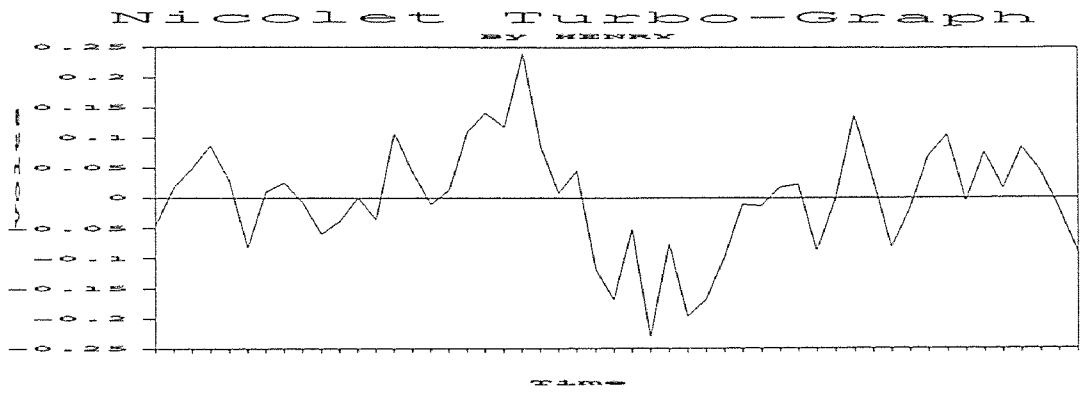
by HENRY
time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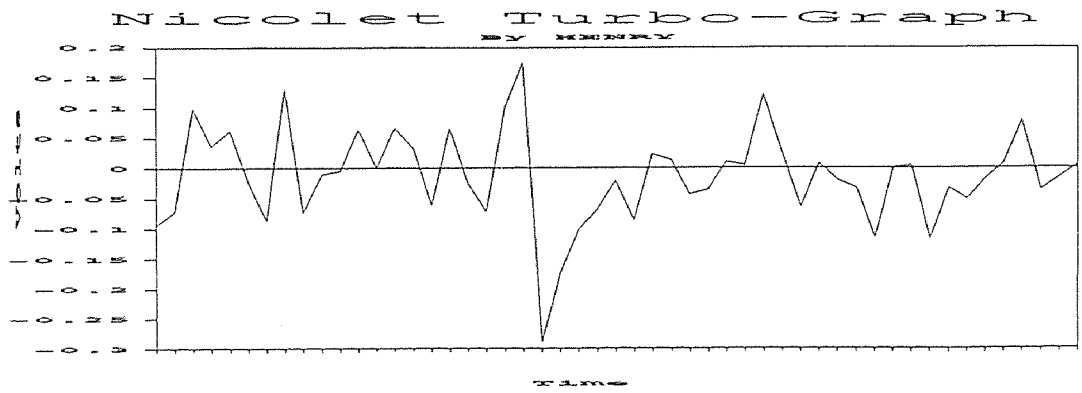
time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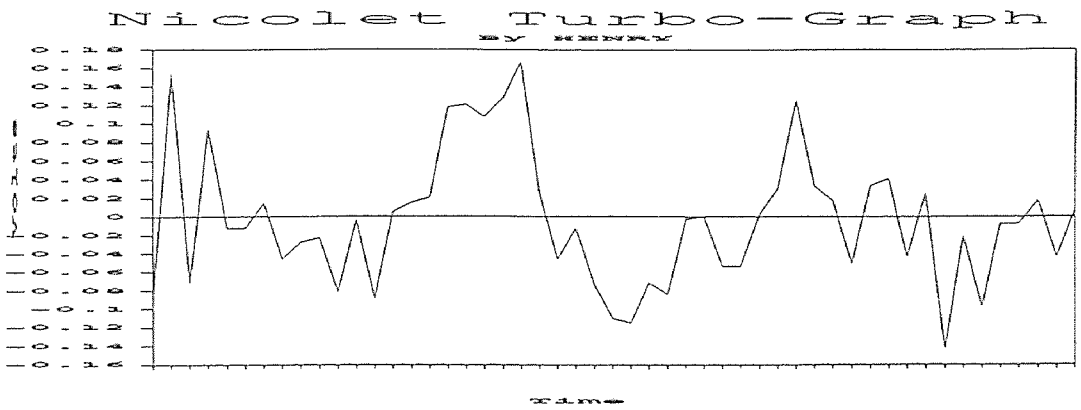
by HENRY
time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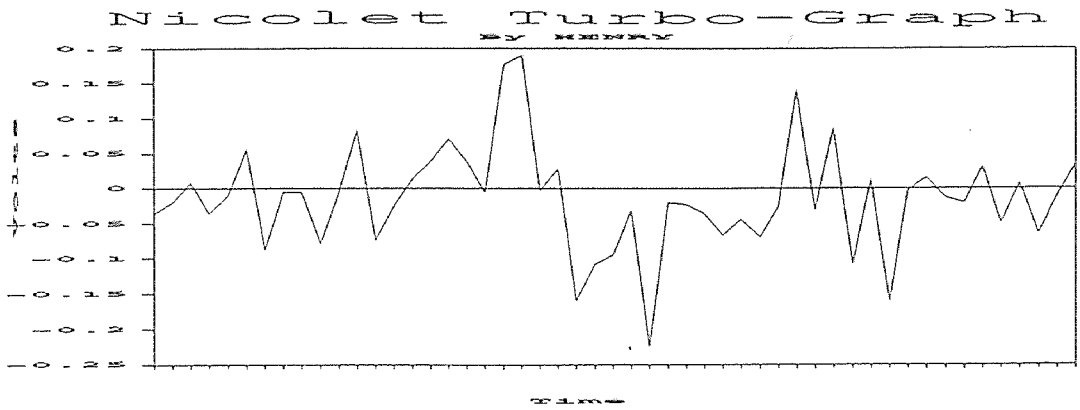
by Henry
time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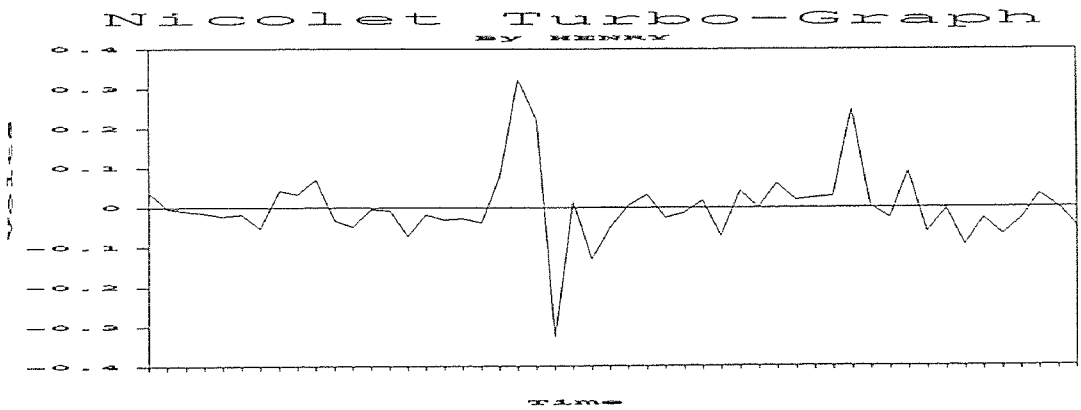
by Henry
time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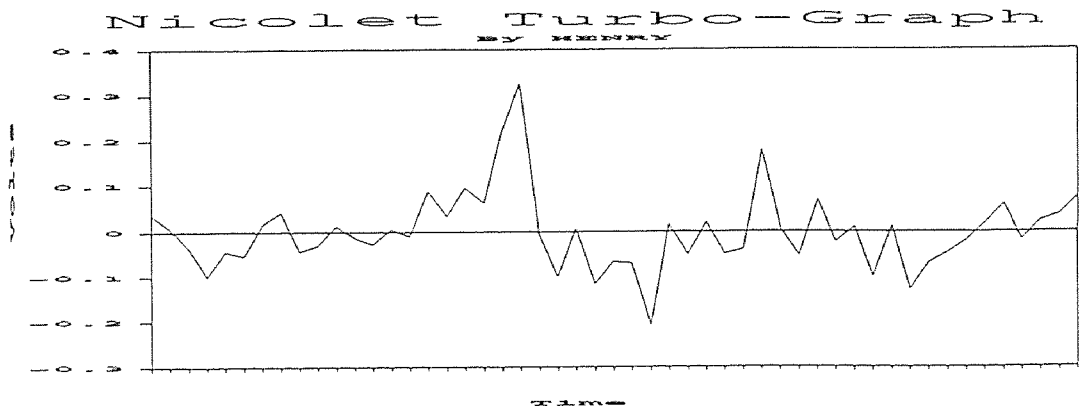
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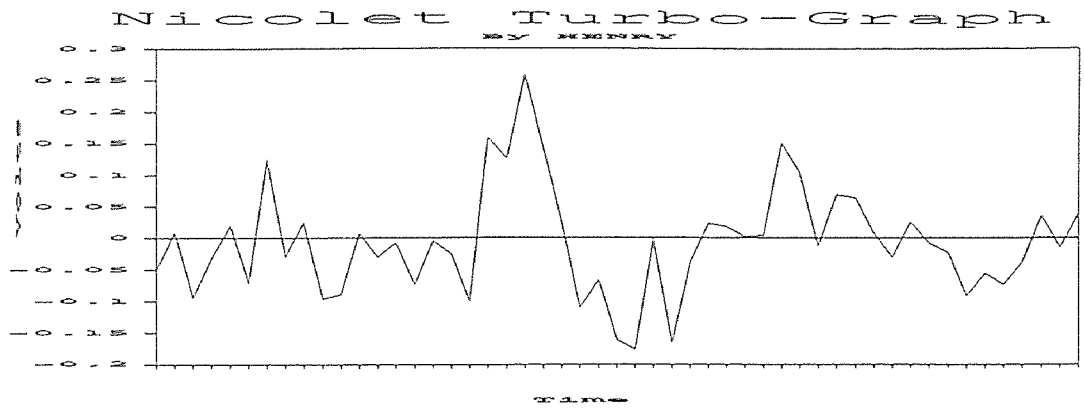
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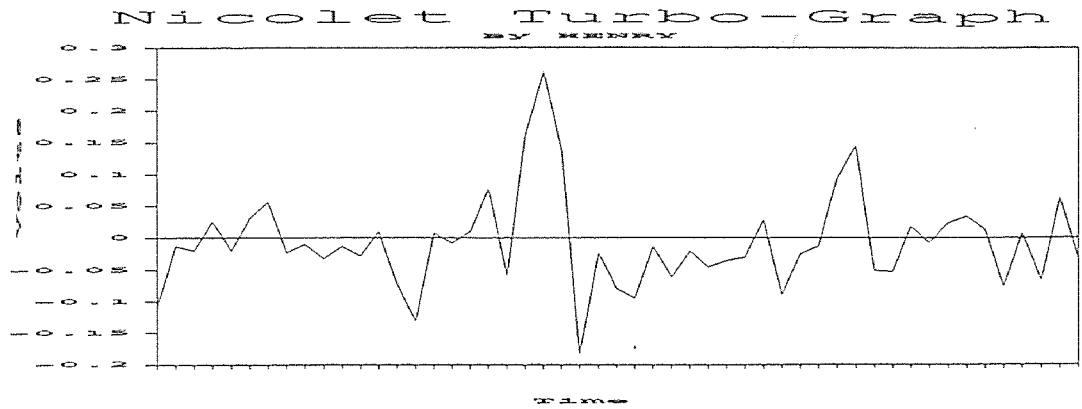
by Henry
time

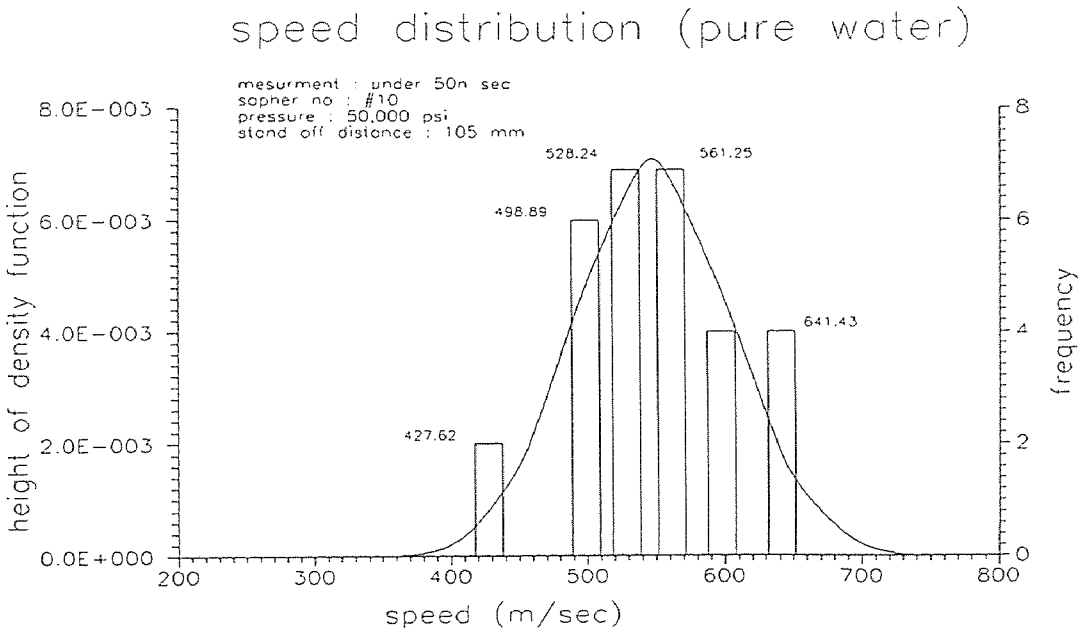

Nicolet Turbo-Graph
by Henry
time

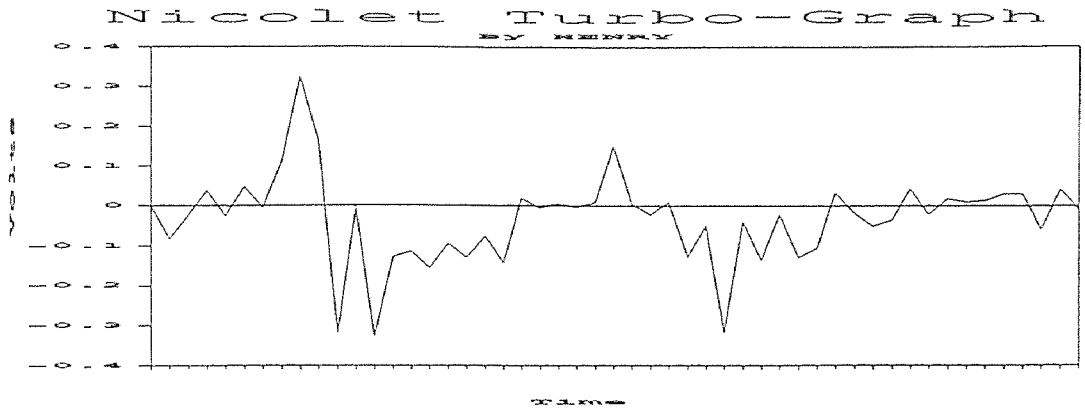
WATER JET VELOCITIES MESUREMENT

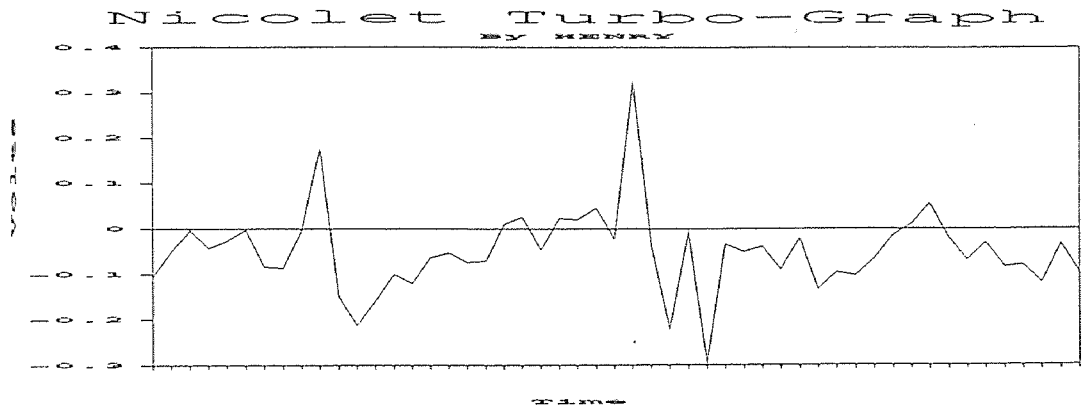
(PURE WATER)

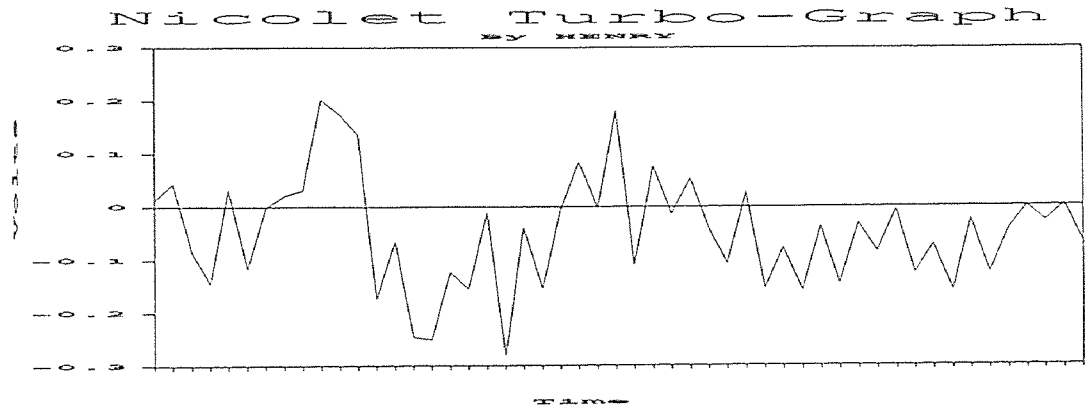
Pressure : 50,000 Psi
Stand Off Distance : 105 mm
Data : 30 Set
Time Base : 50n Sec

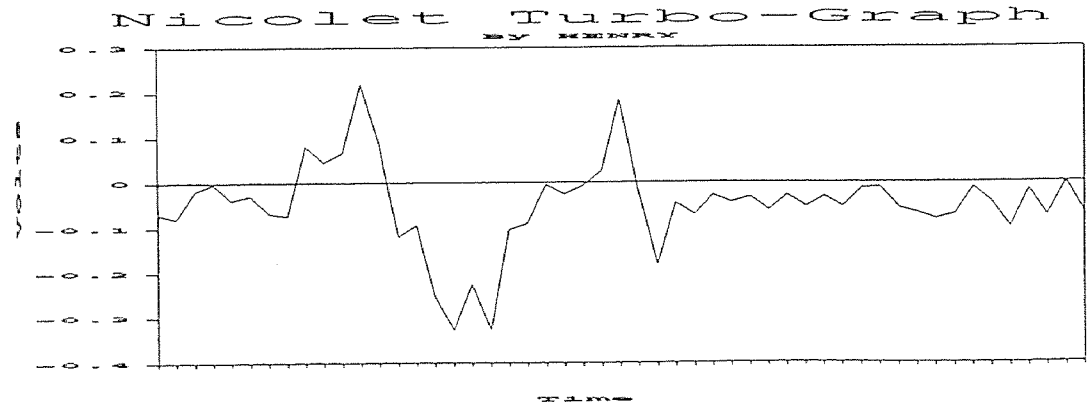
STATISTICS ANALYSIS
Sample Size : 30
Minimum = 427.62
maximum = 641.43
Range = 213.81
Median = 544.745
Arithmetic Mean = 547.847
Geometric Mean = 544.9803
Variance = 3193.149
Standard Deviation = 56.50795
Coefficient of Variation = 10.31455 %
Skewness : Bata (1) = 6.204646E-03 (-)
Kurtosis : Beta (2) = 2.661831

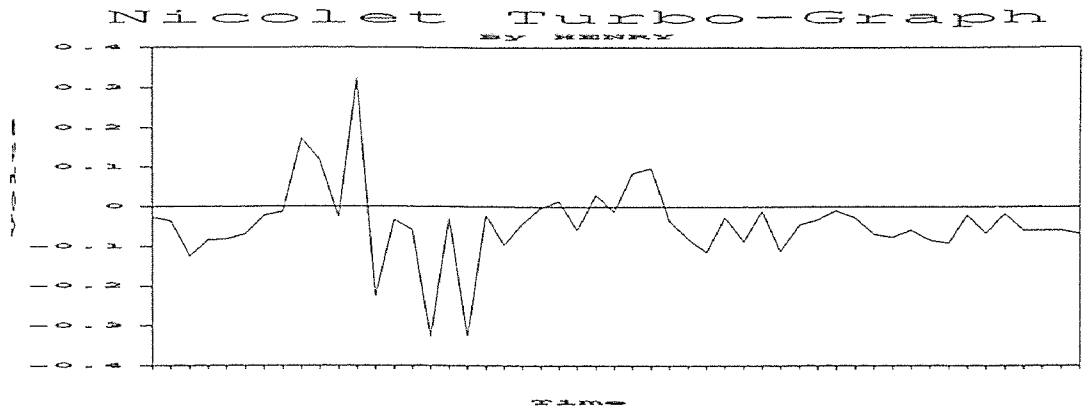



Nicolet Turbo-Graph
by HENRY
time


Nicolet Turbo-Graph
by HENRY
time


Nicolet Turbo-Graph
by HENRY
time


Nicolet Turbo-Graph
by HENRY
time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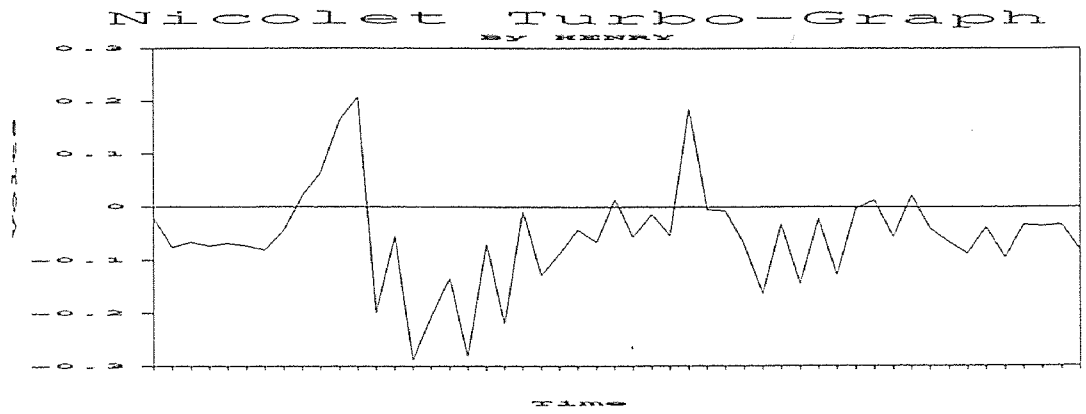
time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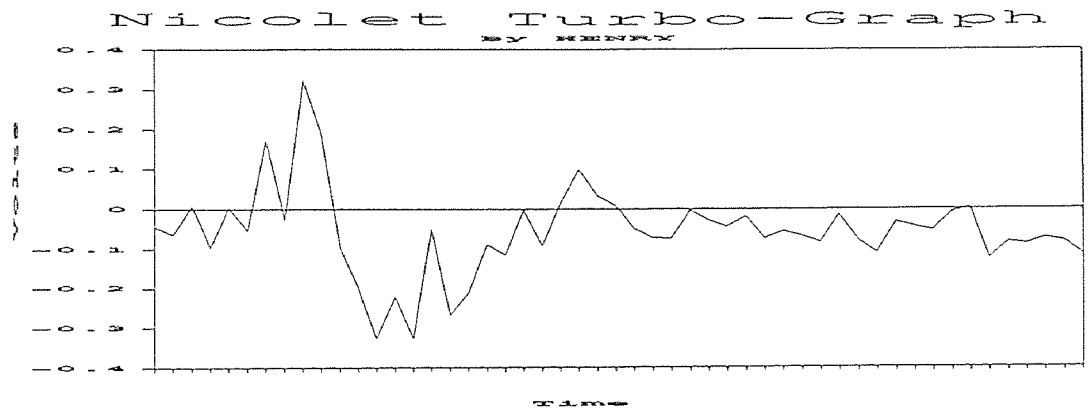
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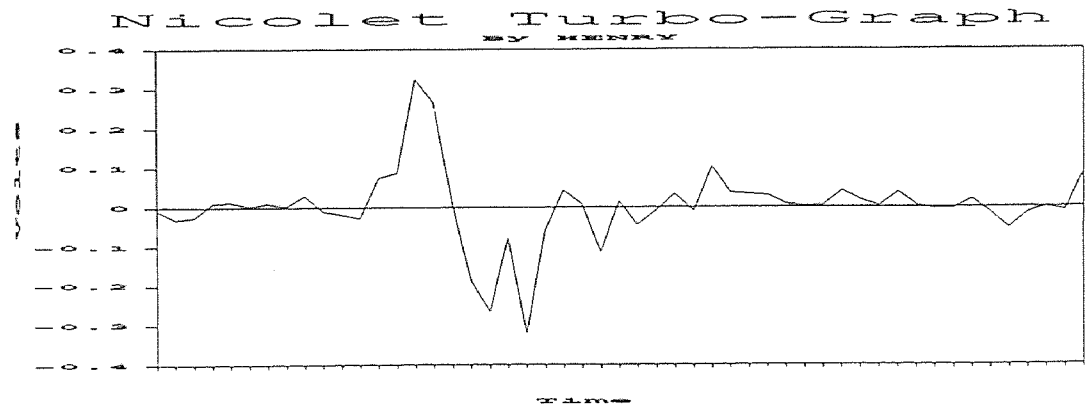
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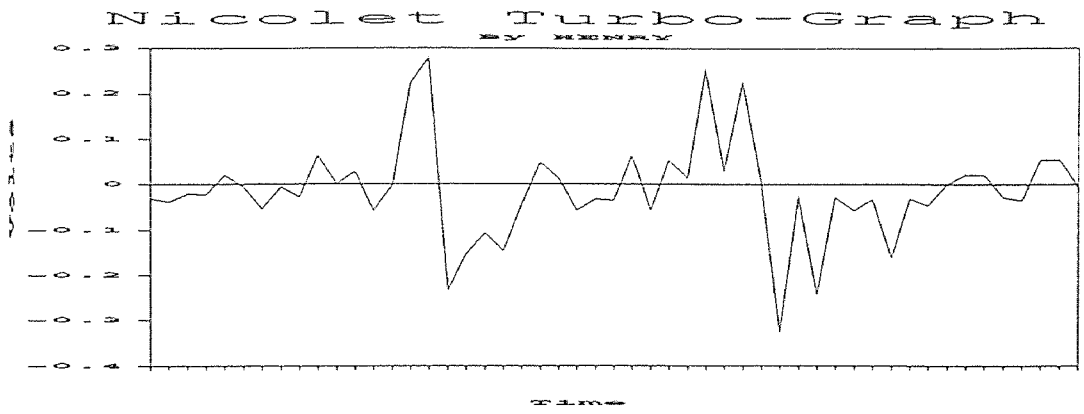
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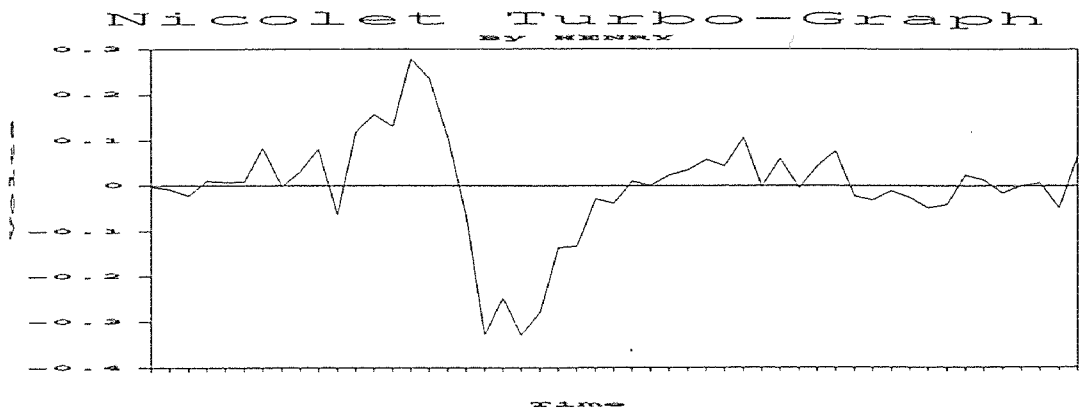
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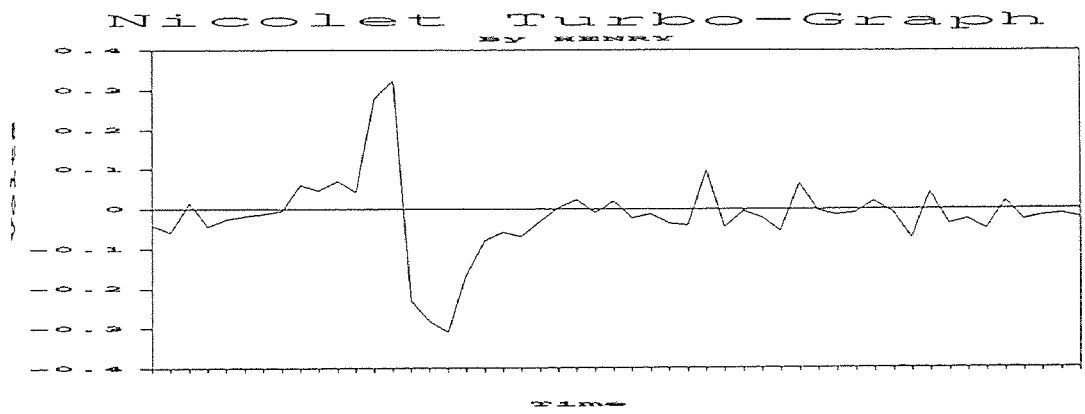
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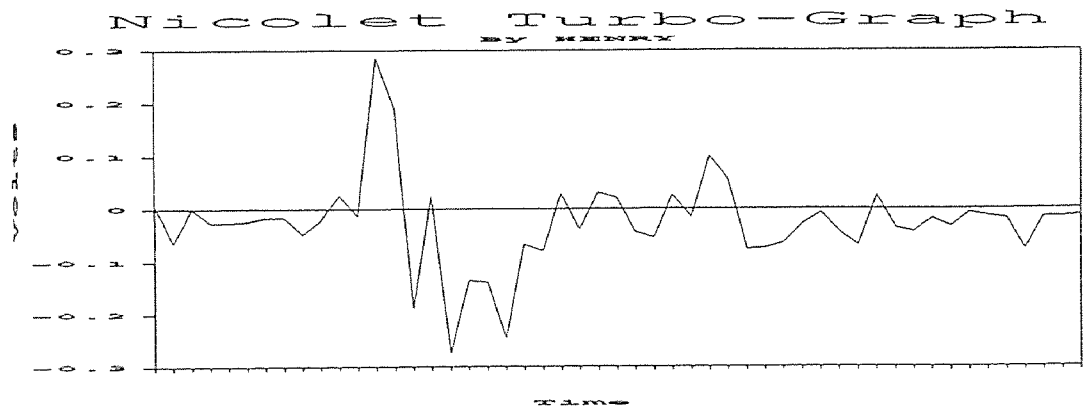
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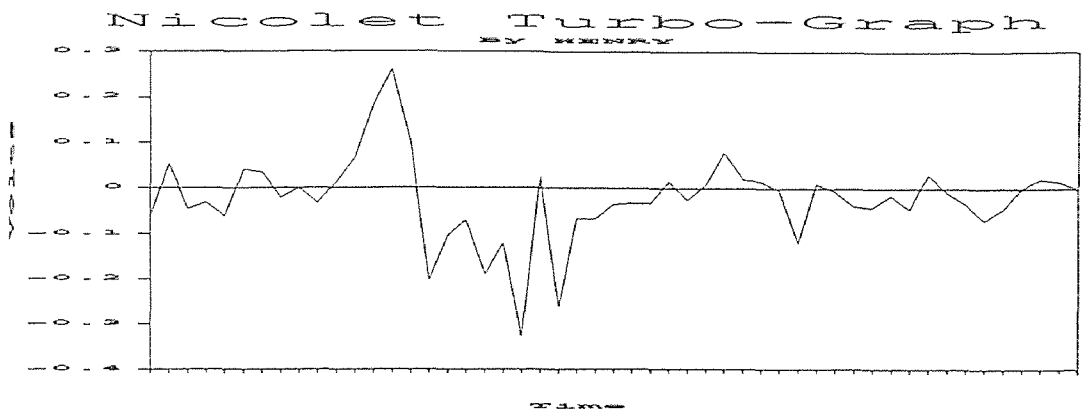
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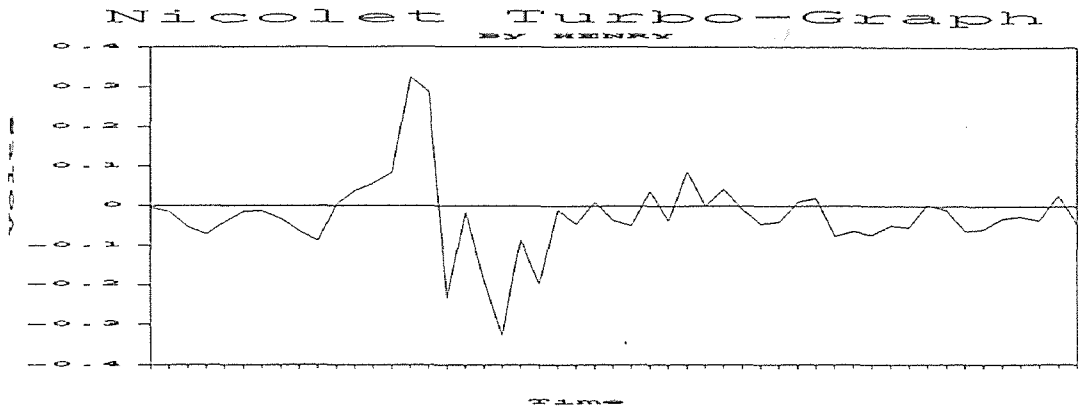
By Henry
Volts
Time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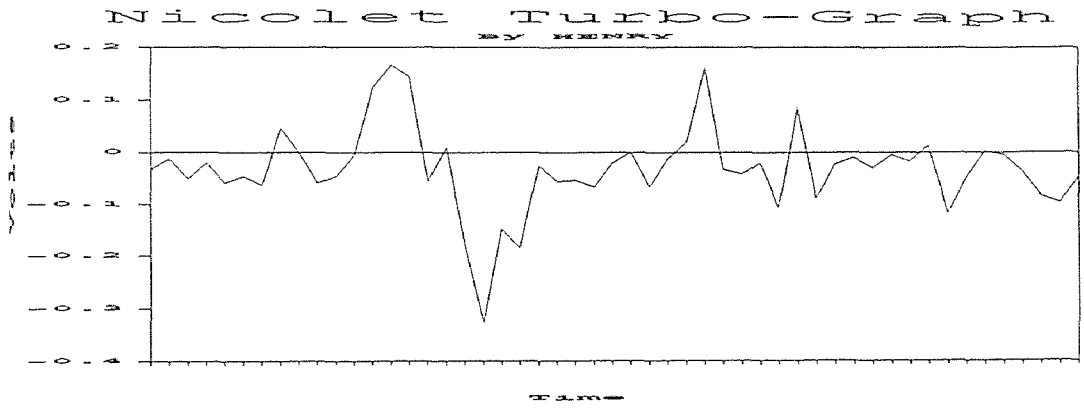
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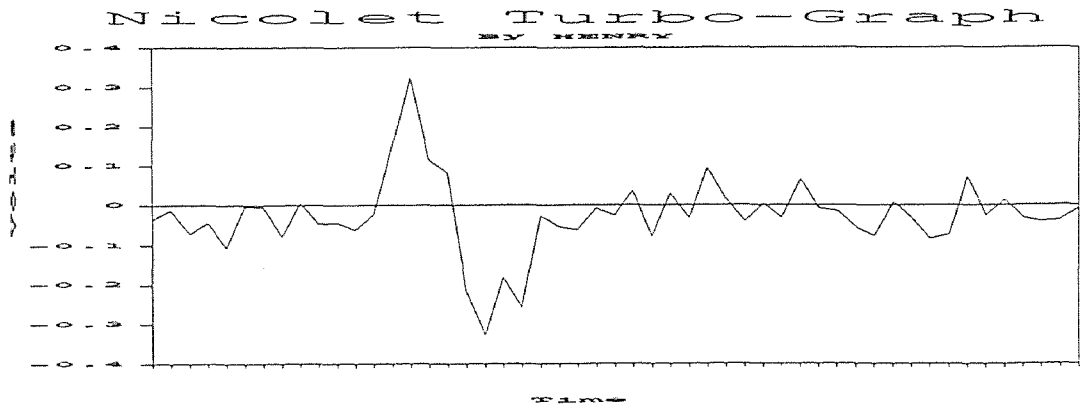
Volts
Time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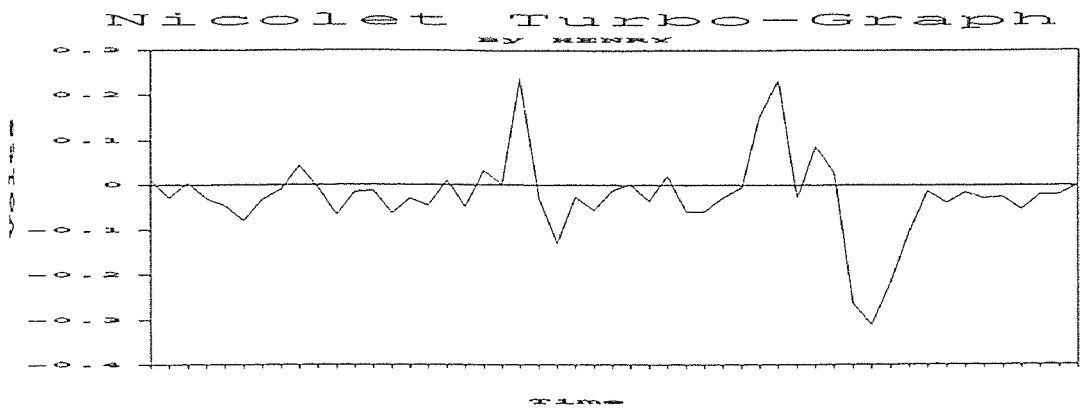
Volts
Time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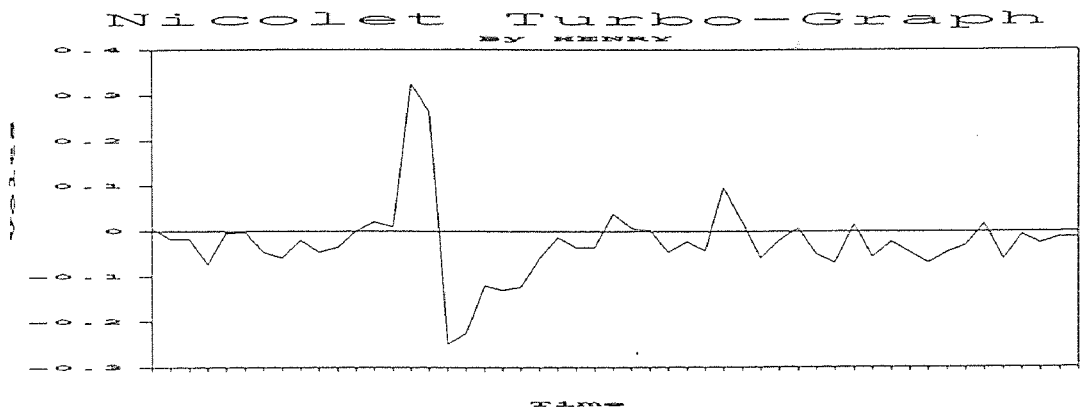
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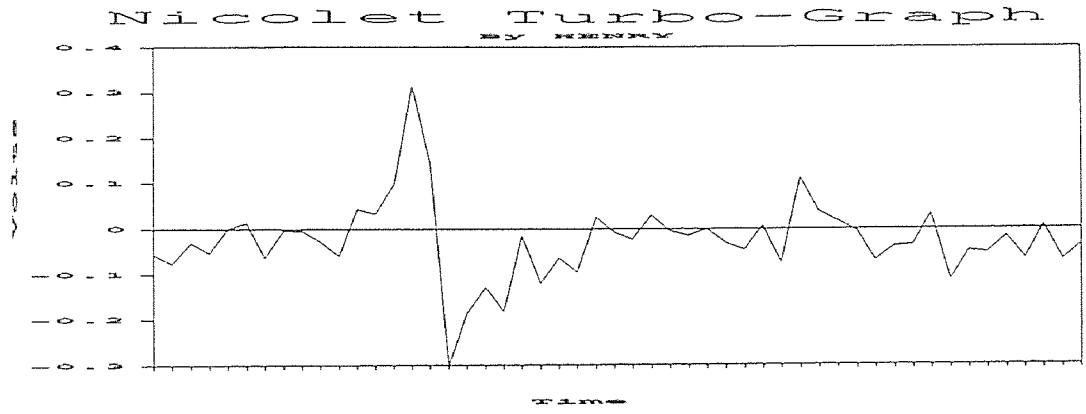
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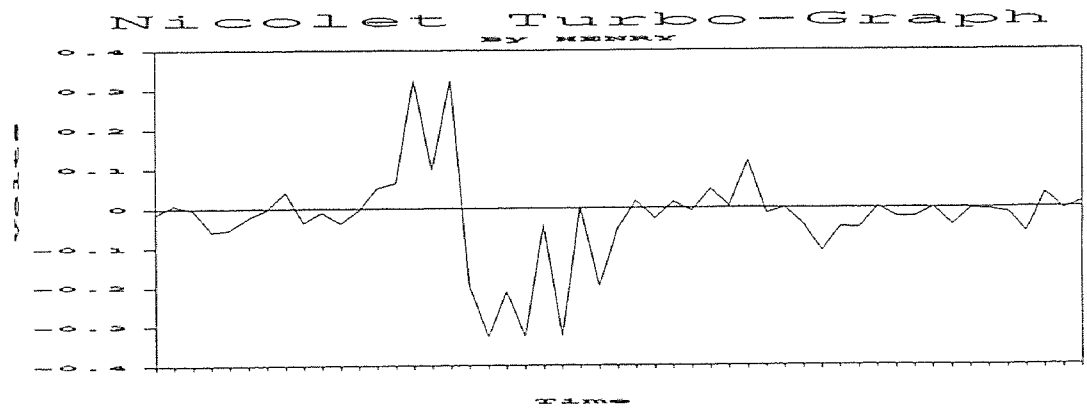
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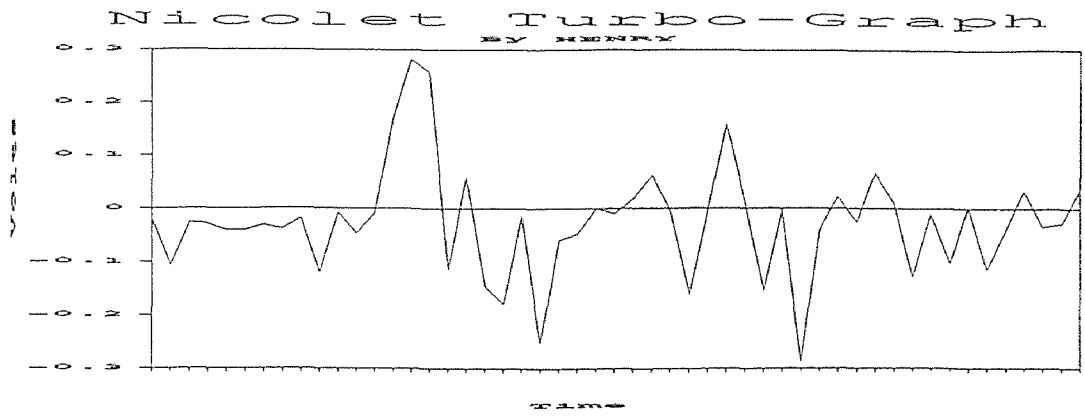
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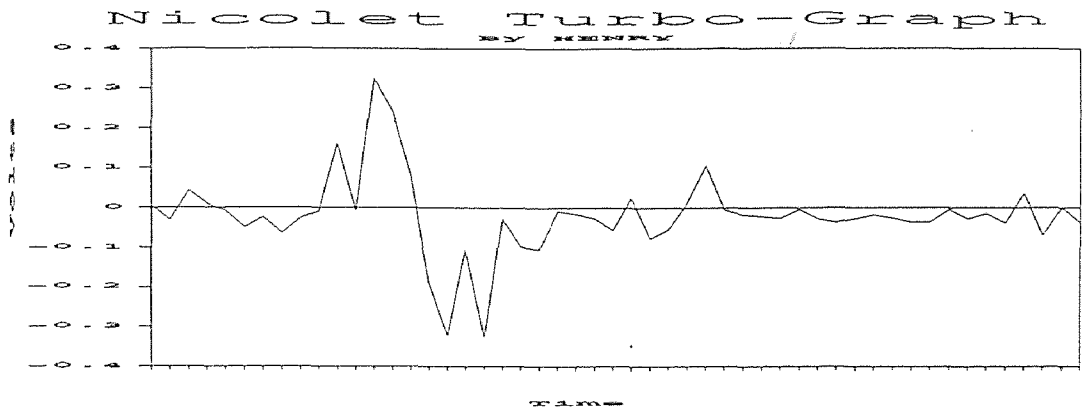
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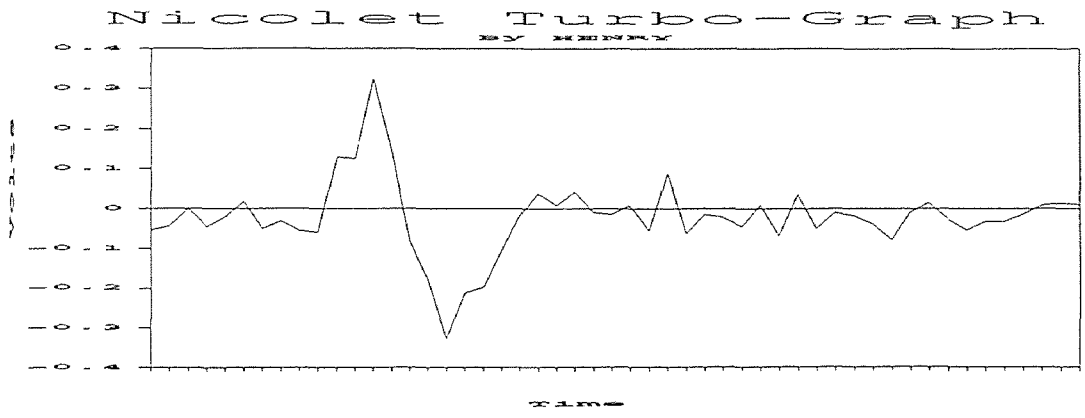
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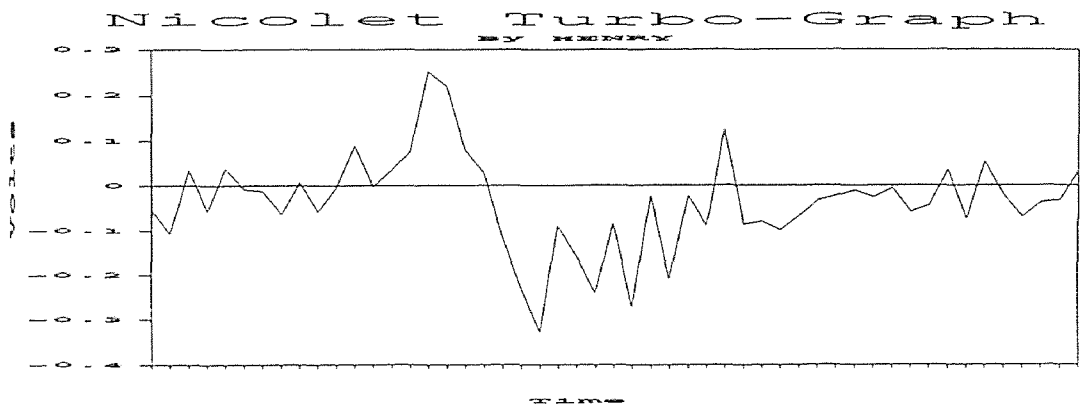
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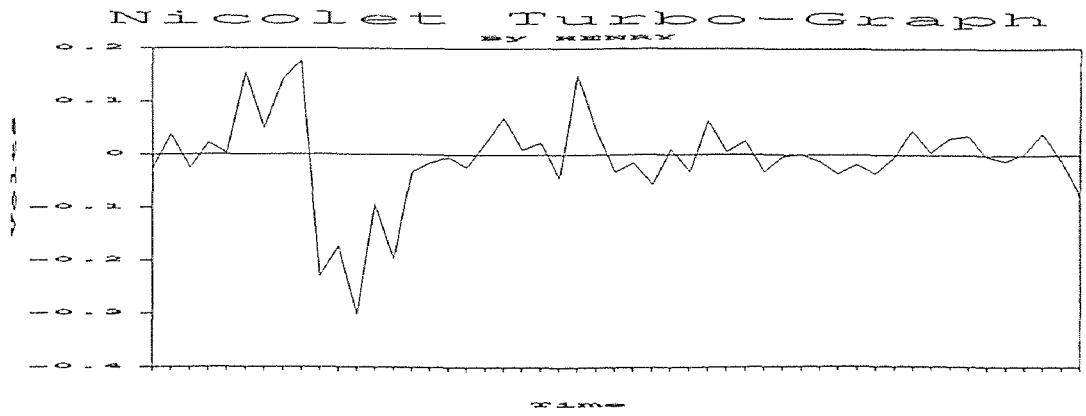
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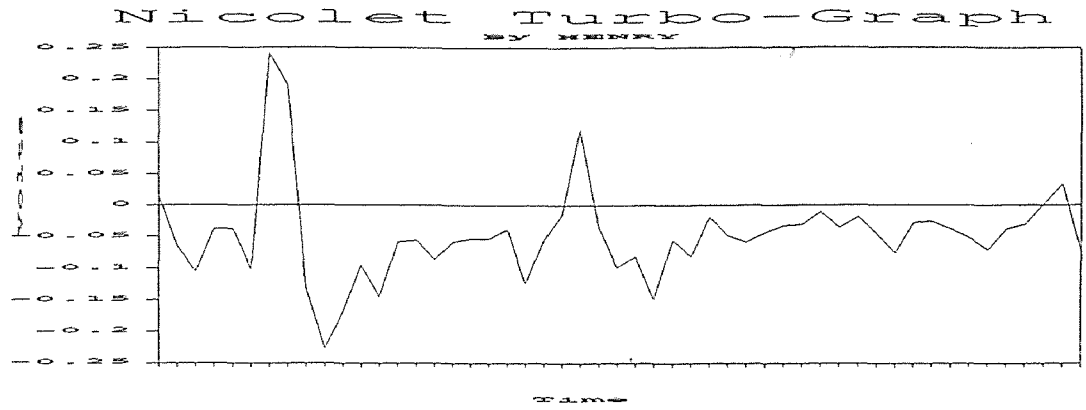
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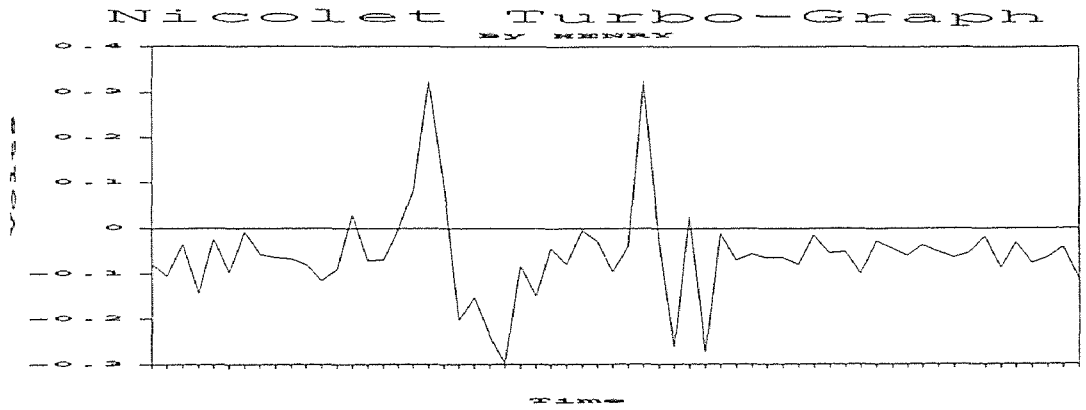
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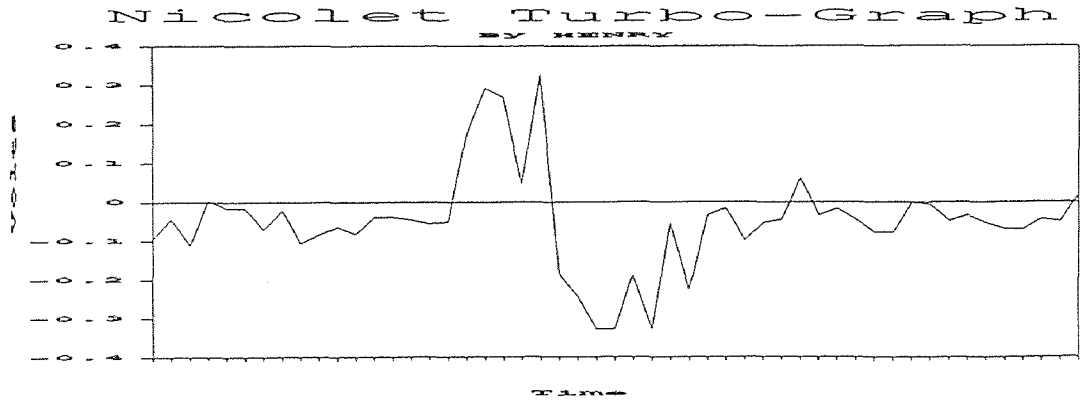
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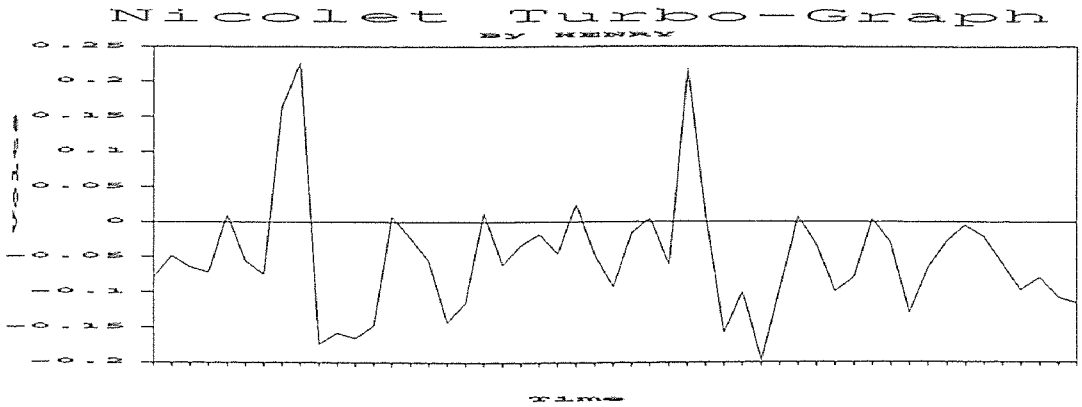
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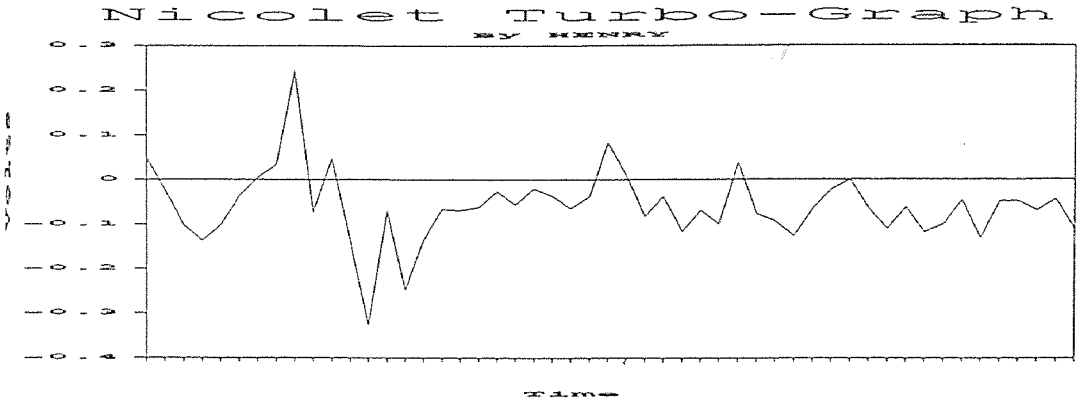
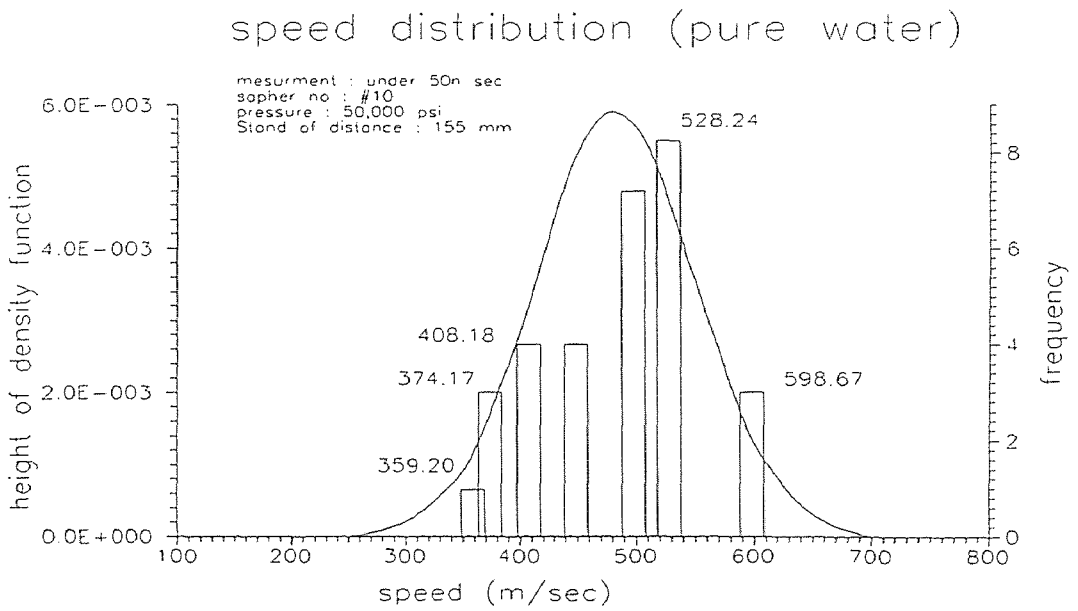

Nicolet Turbo-Graph
by HENRY
time

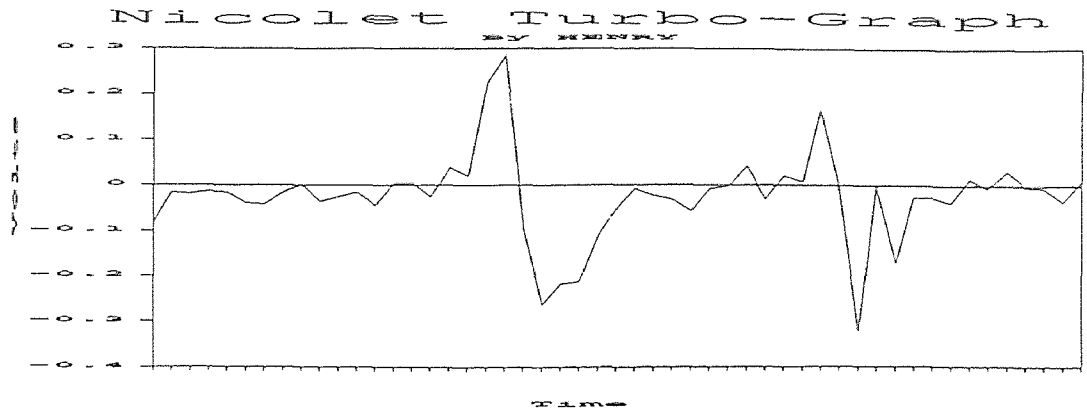
WATER JET VELOCITIES MESUREMENT

(PURE WATER)

Pressure : 50,000 Psi
Stand Off Distance : 155 mm
Data : 30 Set
Time Base : 50n Sec

STATISTICS ANALYSIS
Sample Size : 30
Minimum = 359.2
maximum = 598.67
Range = 239.47
Median = 498.89
Arithmetic Mean = 482.1804
Geometric Mean = 477.4769
Variance = 4541.089
Standard Deviation = 67.3876
Coefficient of Variation = 13.9756 %
Skewness : Bata (1) = 2.788561E-02 (-)
Kurtosis : Beta (2) = 2.10681

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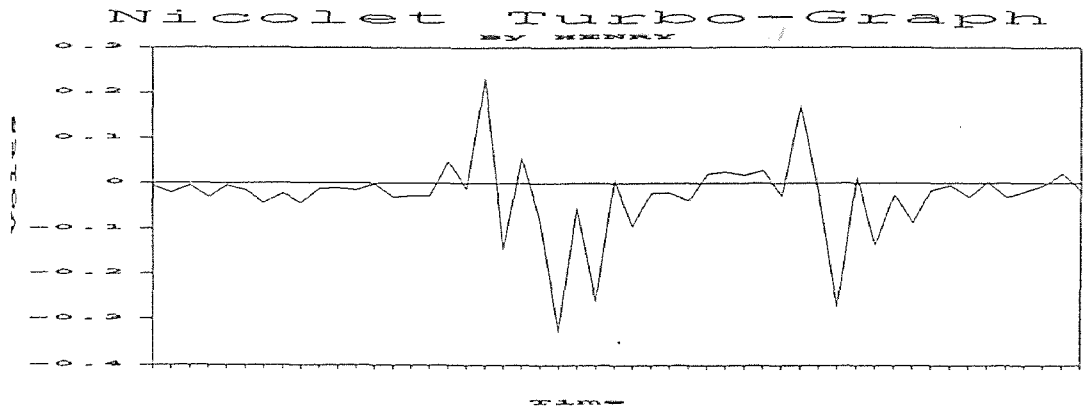
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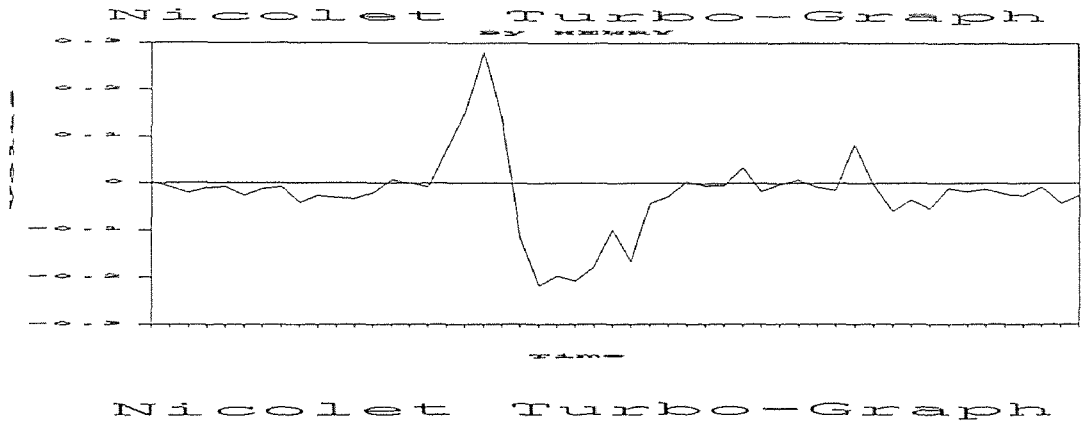
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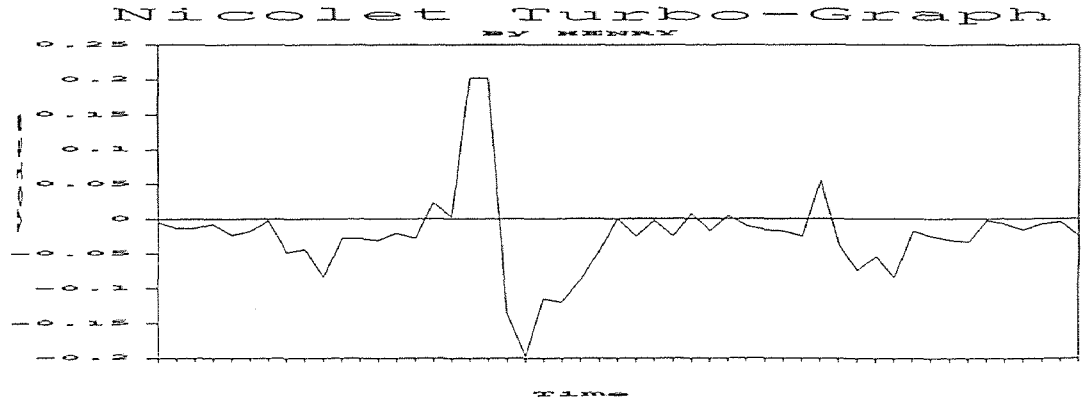
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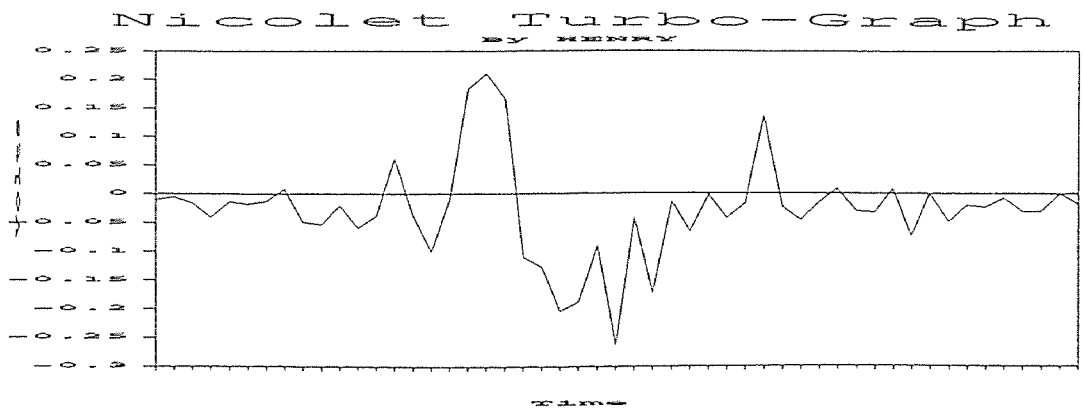
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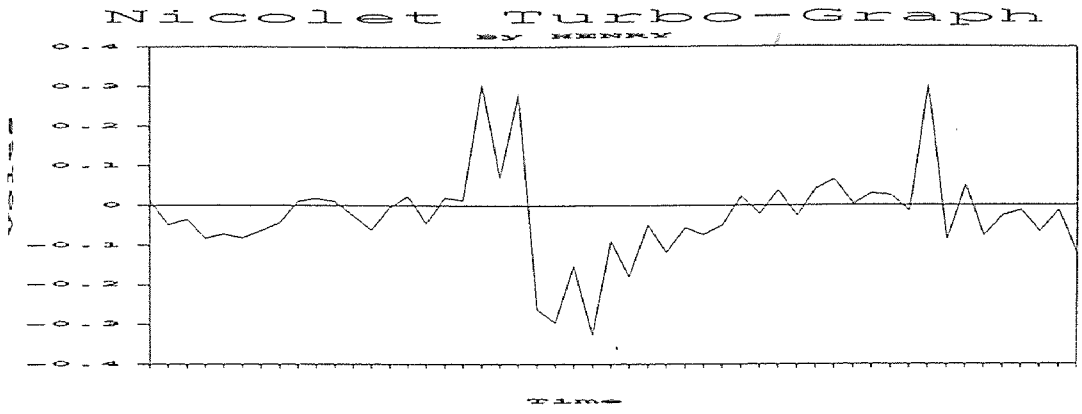
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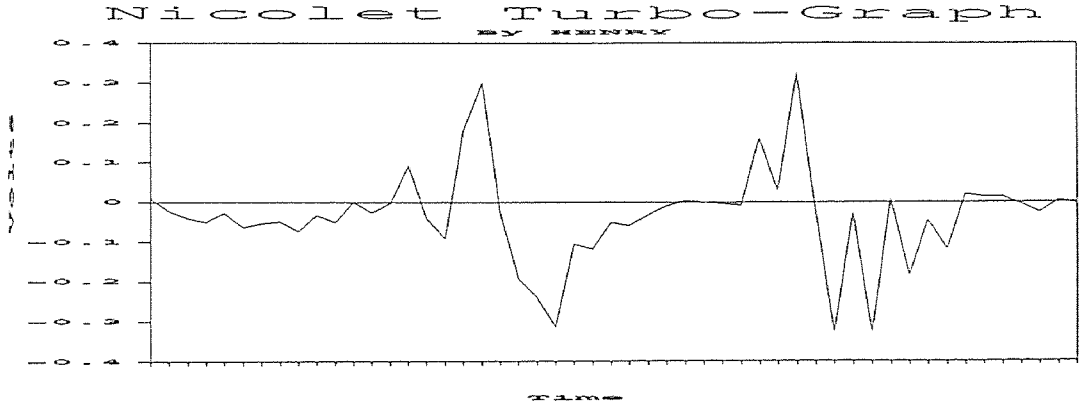
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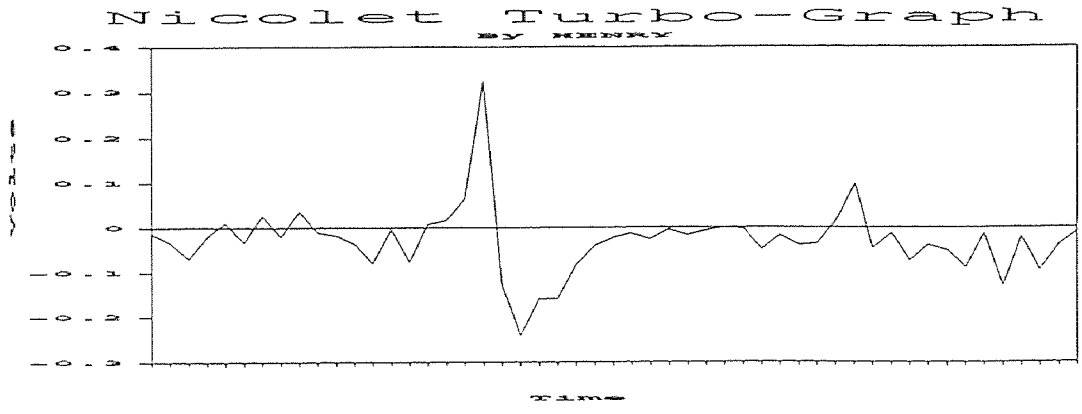
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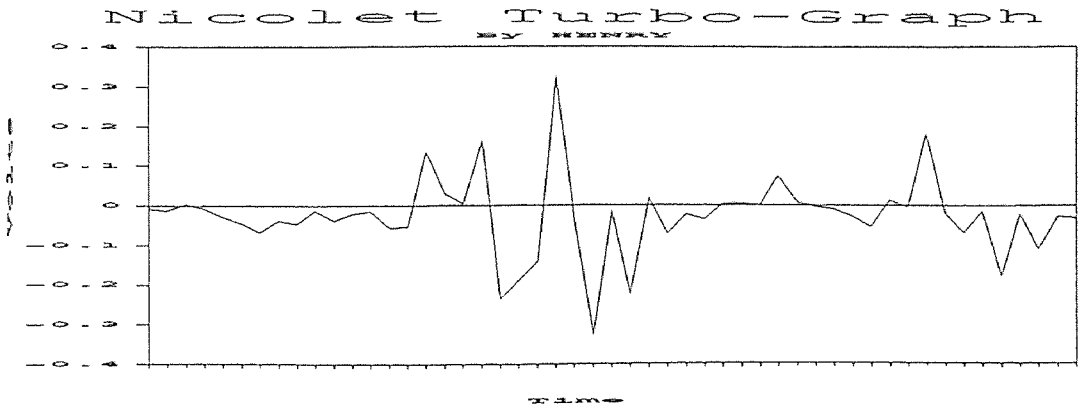
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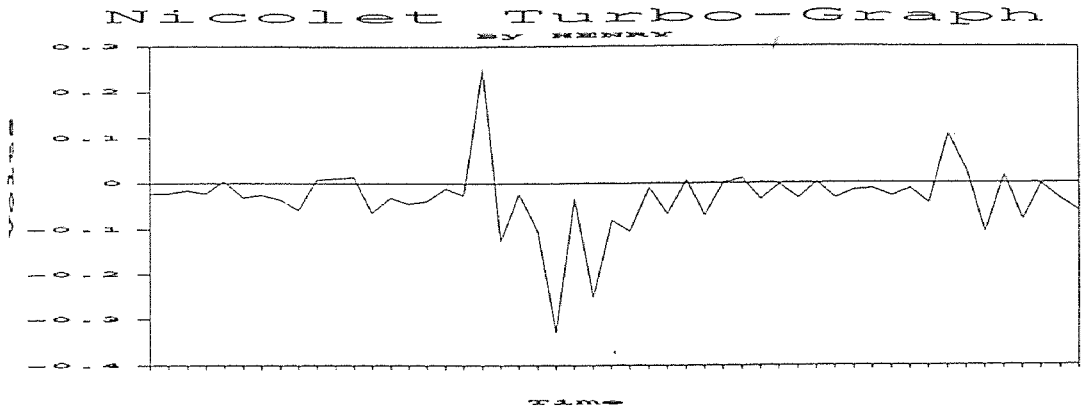
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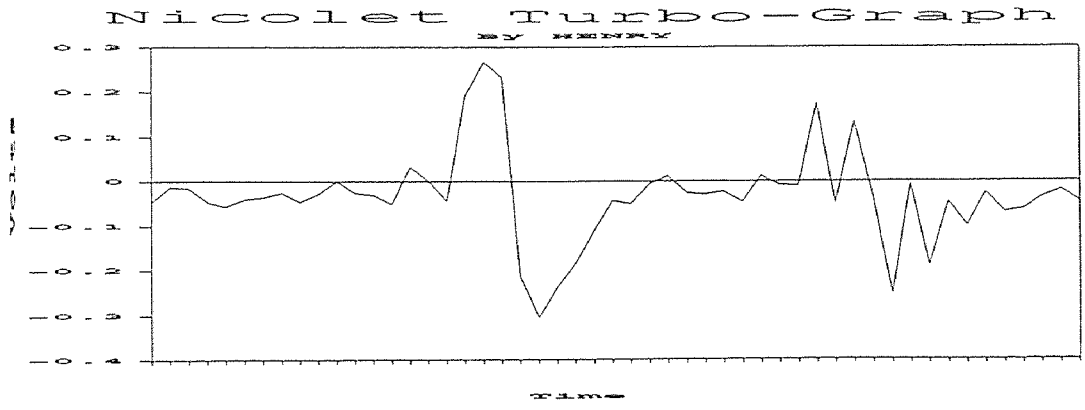
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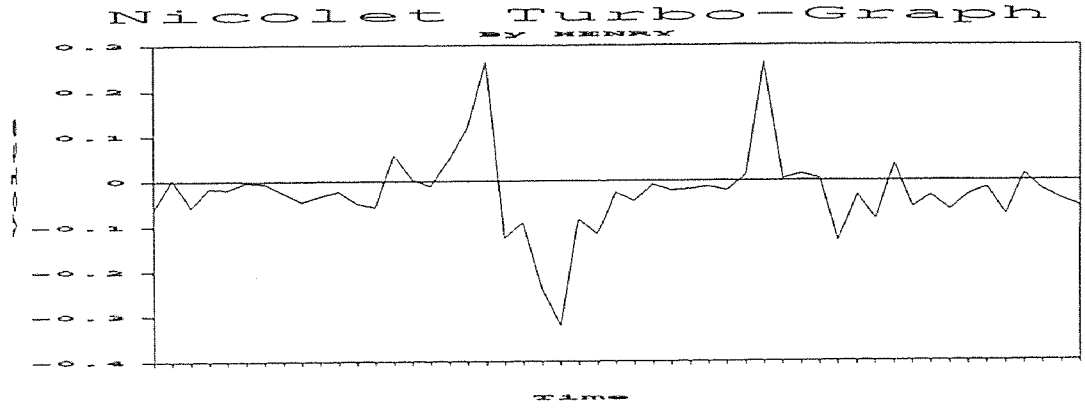
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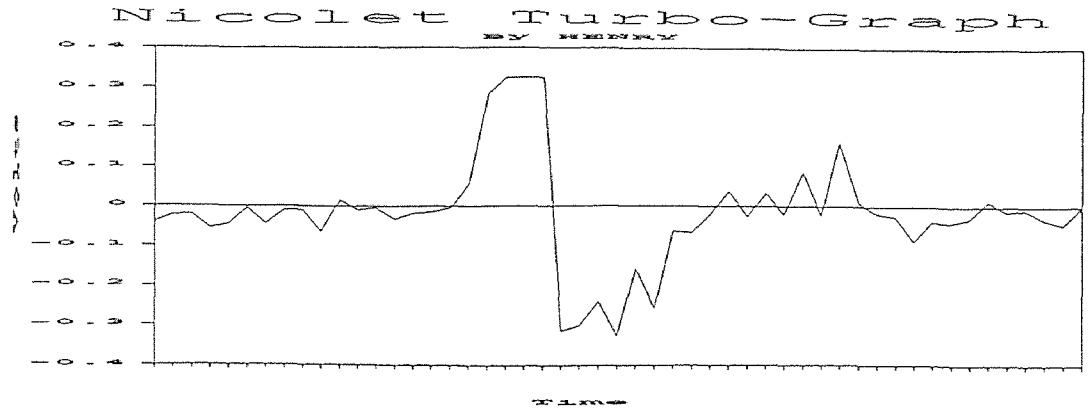
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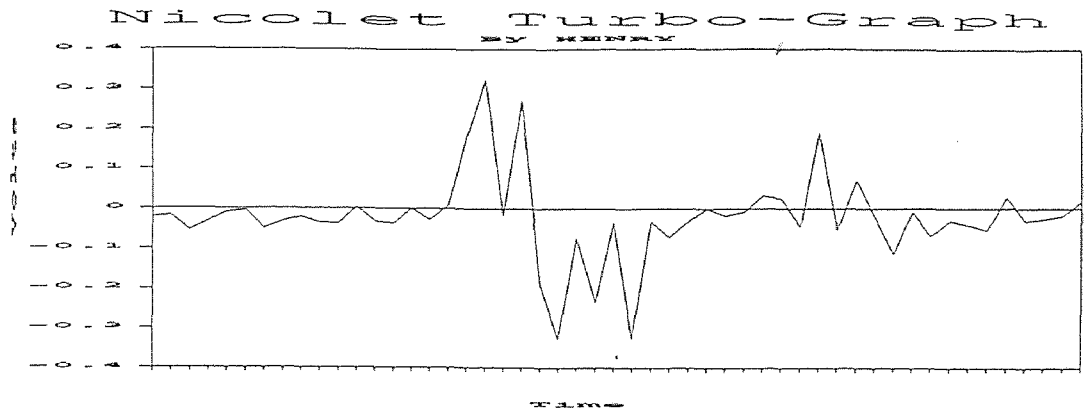
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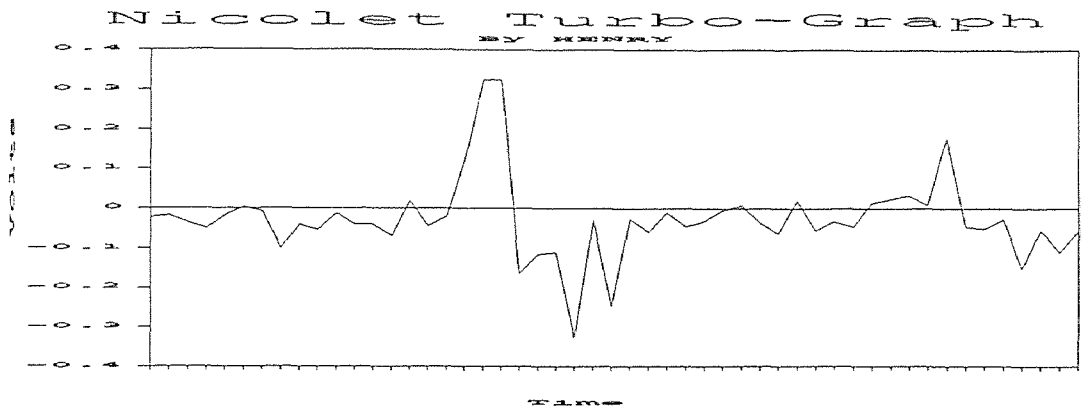
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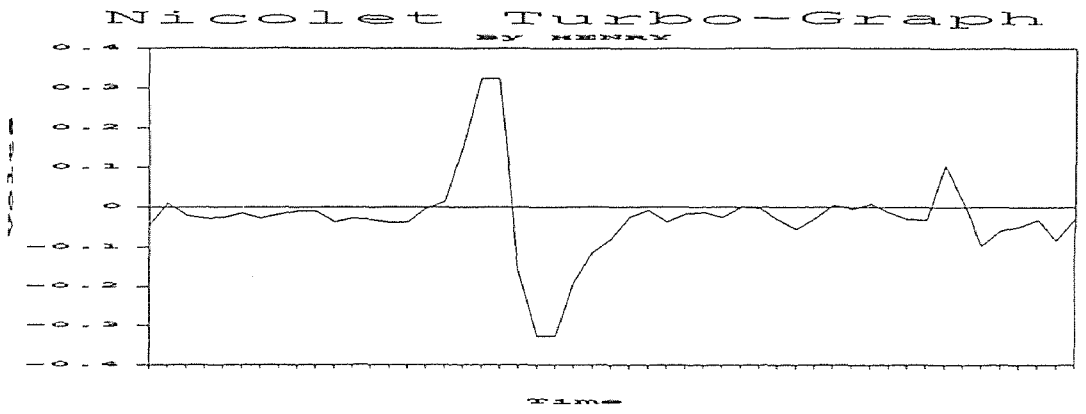
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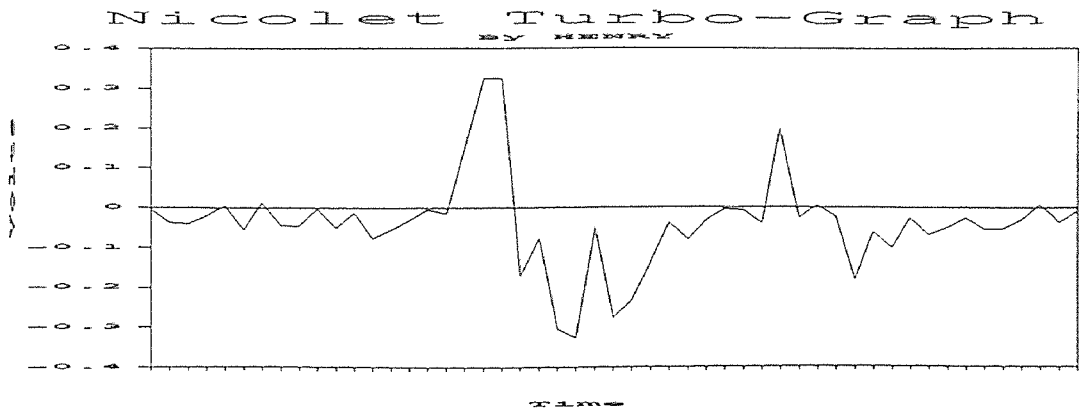
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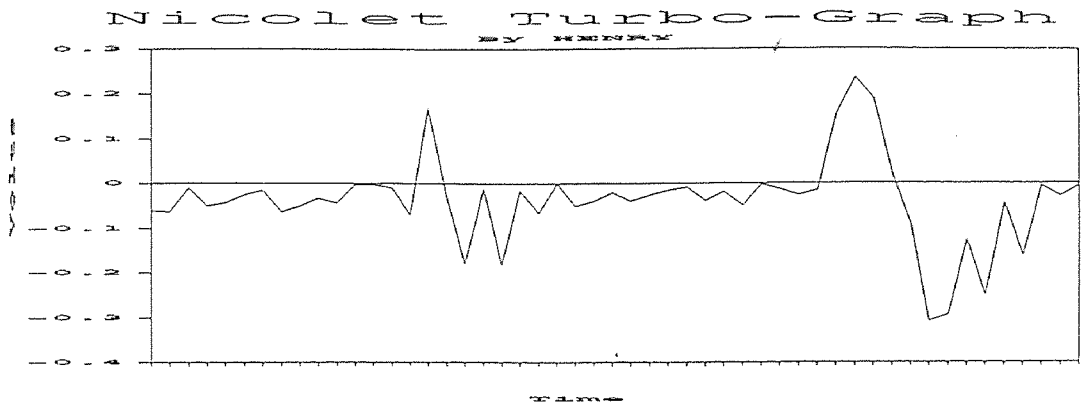
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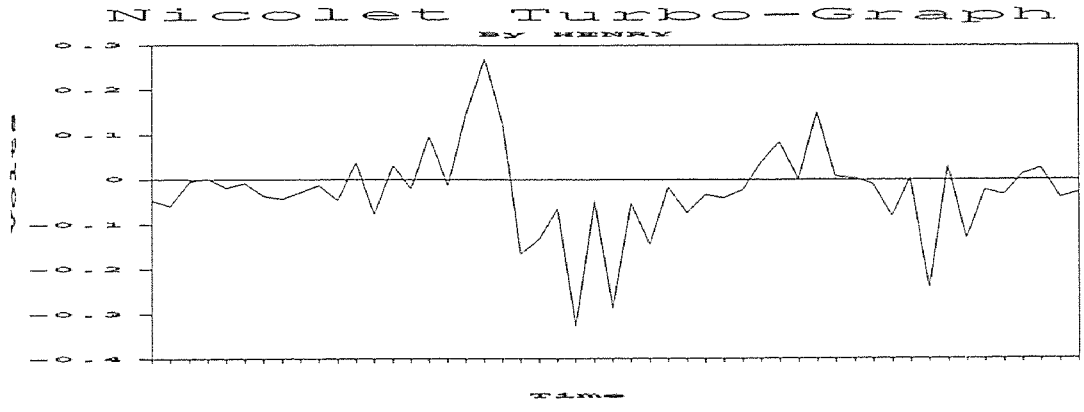
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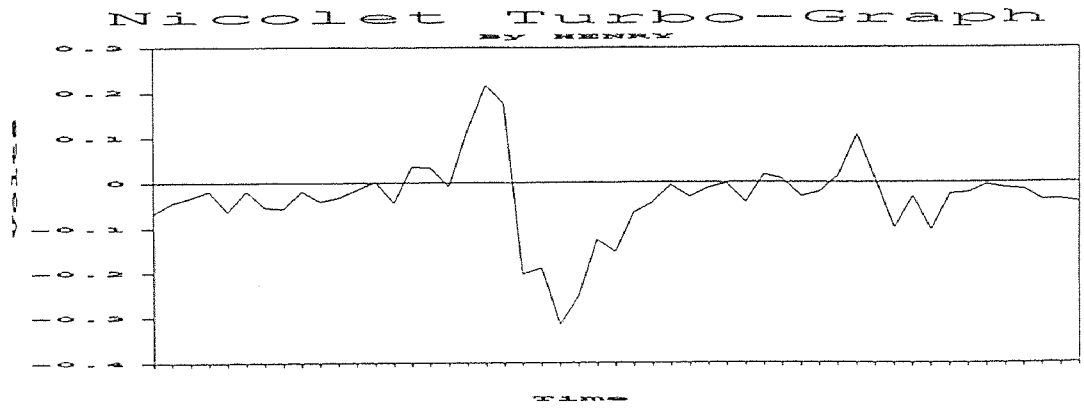
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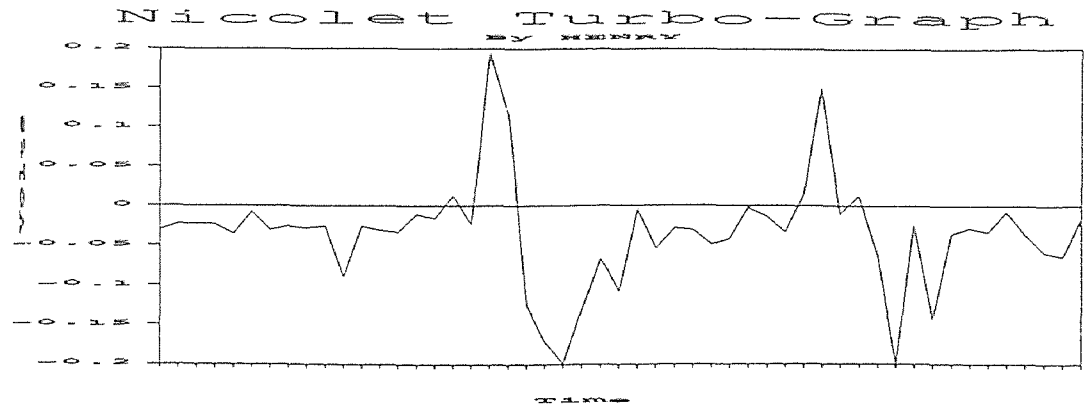
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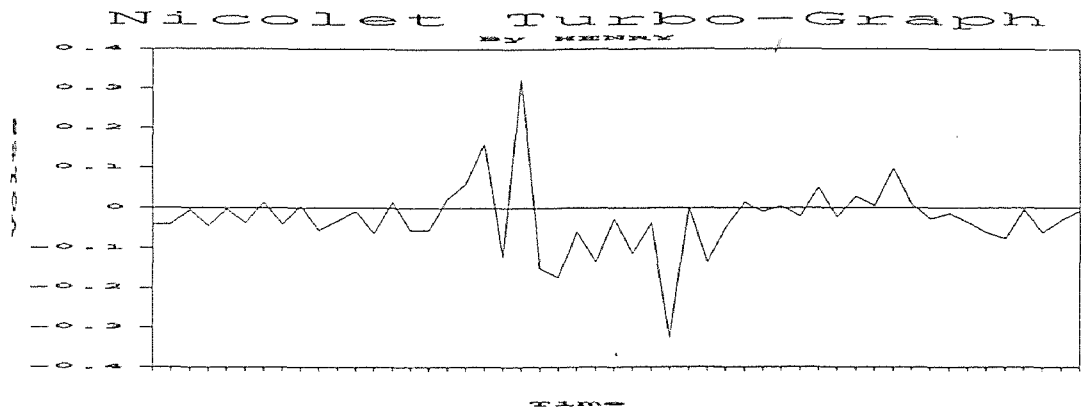
Nicolet Turbo-Graph
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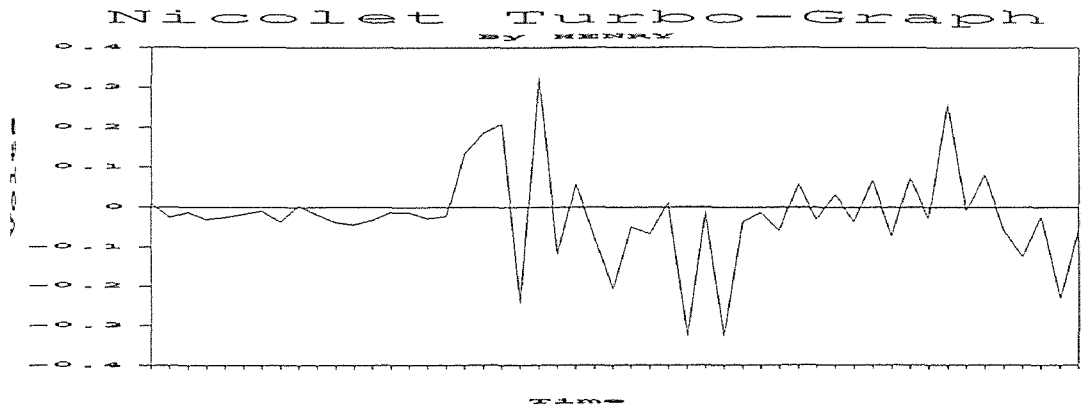
time


Nicolet Turbo-Graph
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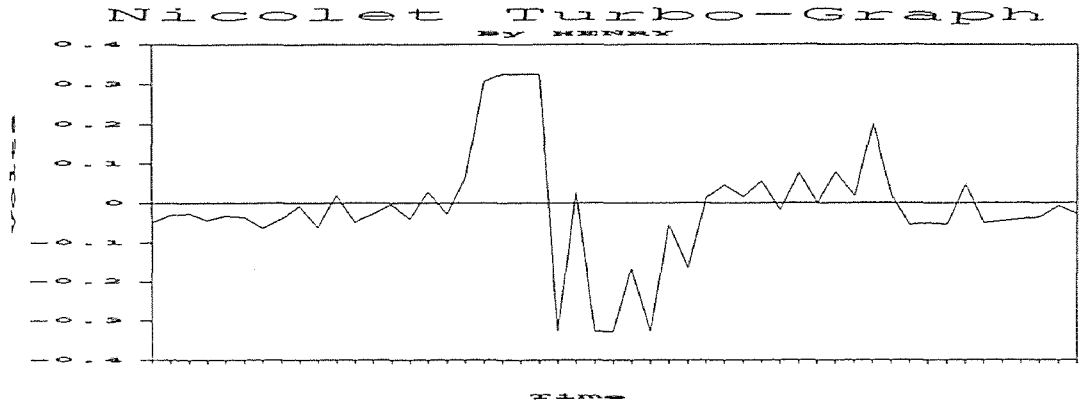
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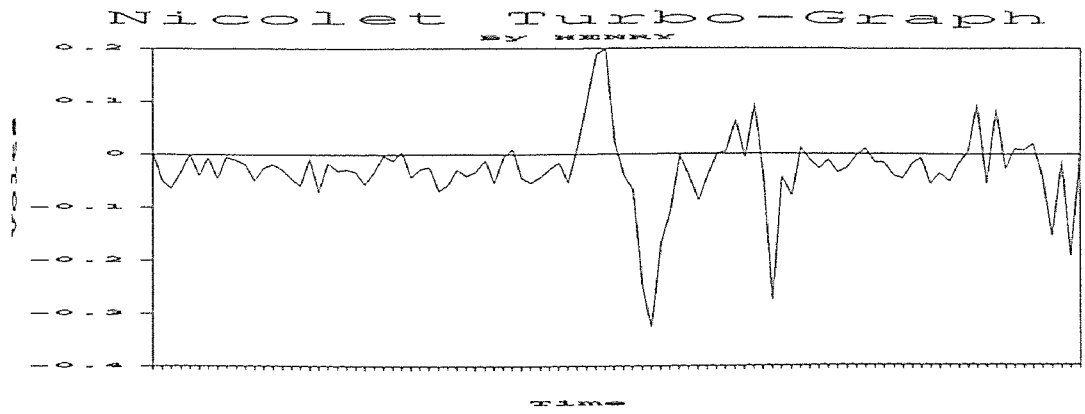
Nicolet Turbo-Graph
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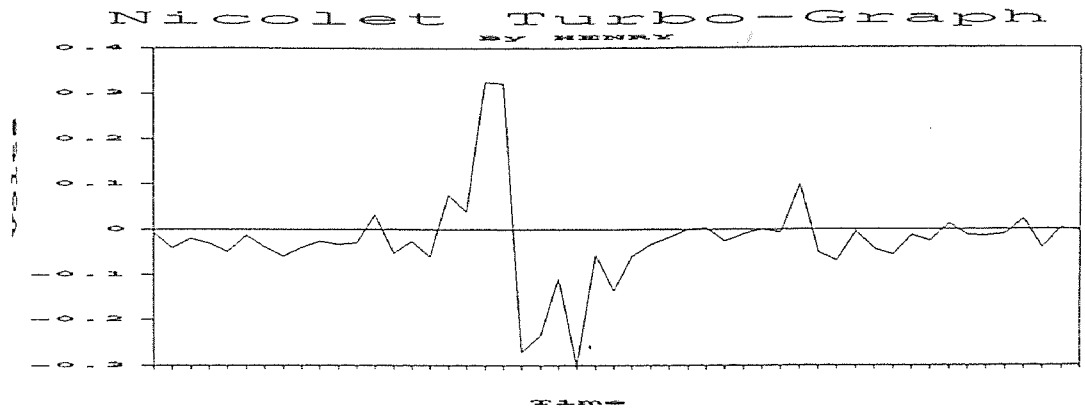
volts
time


Nicolet Turbo-Graph
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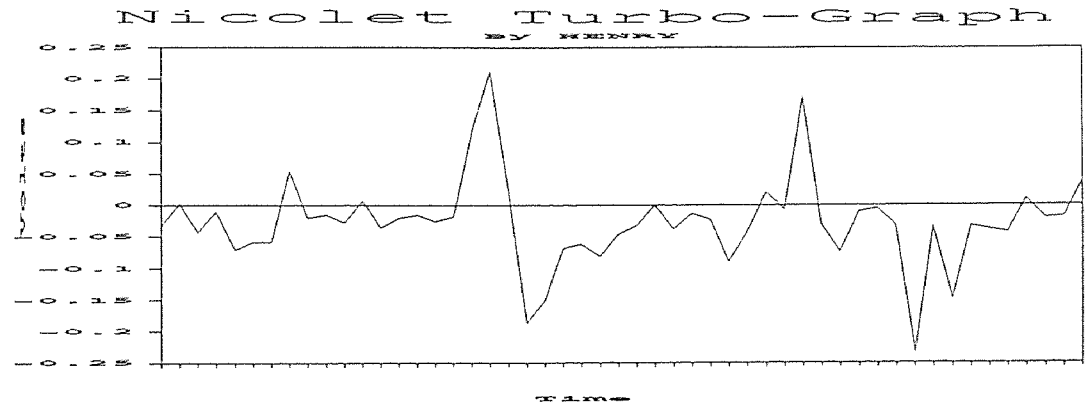
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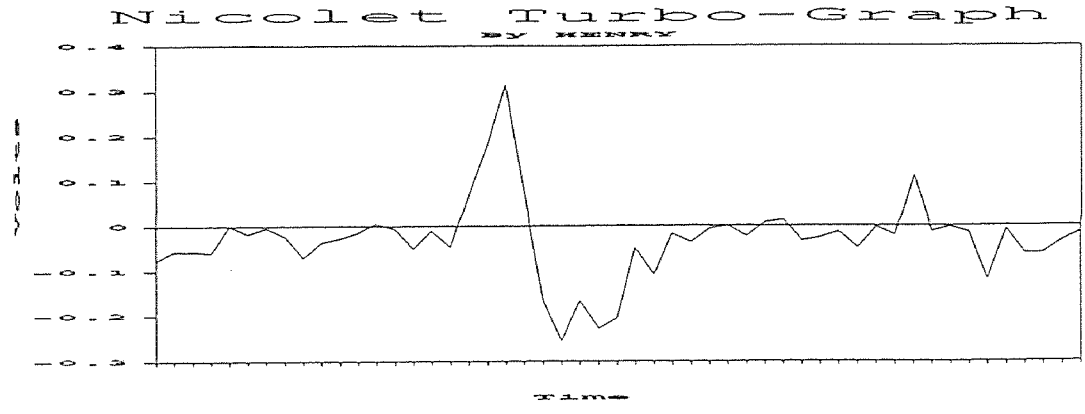
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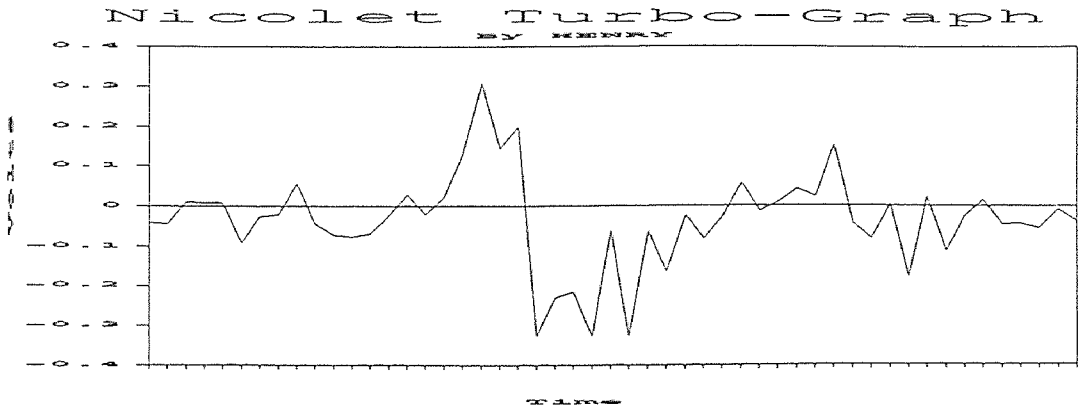
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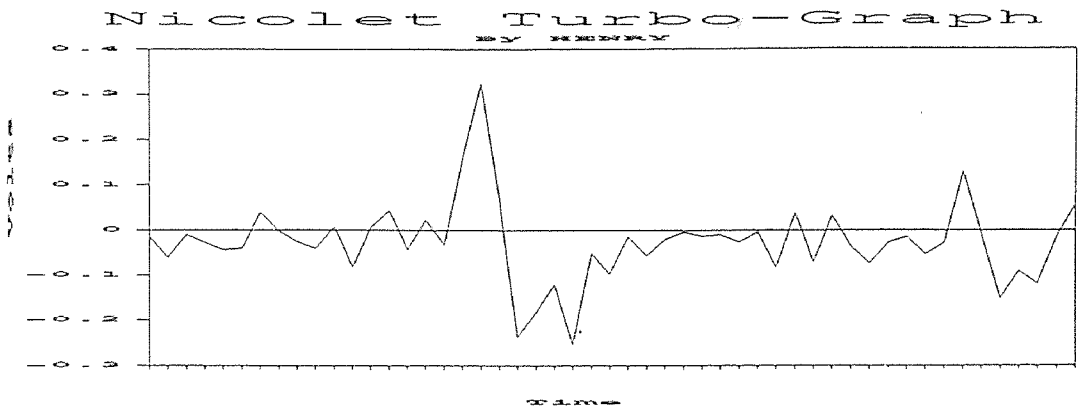
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