SPPE-1000 Product Manual

NanoWave Inc

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Revision History		
Rev. 1	2/5/08	Update
Rev. 2	6/9/08	Update
Rev. 3	8/8/08	Update
Rev. 4	9/30/08	Update
Rev. 5	10/06/08	Error corrections

Contents

1 Overview of SPPE-1000 System

Figure 1: SPPE Photos

Features of SPPE-1000 System

1. Reflective diffraction position encoder based on NanoWave's Scanning Probe Position Encoder (SPPE) technology (www.nanowave.com)
2. 2μm signal pitch with **7.6 pico-meters** resolution
3. FPGA based signal processing core, achieving fast and customizable performance
4. Optical fiber guided light source virtually eliminating the heat source near measurement environment
5. Differential measurement with an integrated reference scale for long-term stability
6. Long working distance (**2.4mm**) between the head and the scale for easy set-up
7. Wide set-up tolerance

The SPPE-1000 system is an atomic scale (better than 0.01nm), ultra-precision position encoder based on NanoWave's patents and FPGA engine, developed in part through collaboration with Nikon Corp. in Japan. It also incorporates numerous new technologies such as a MEMS laser scanning mirror, a Super Luminescent Diode (SLD) light source, and an optical fiber guided light source in a compact and low cost package.

Nikon's new optical design combined with NanoWave's signal processing technology has enabled a long working distance and a wide set-up tolerance which is superior to the typical sub-micron resolution optical encoders, despite its extreme measurement resolution and accuracy. As a result, no special skill other than the ones typically required for sub-micron precision machine design is necessary to obtain the highest performance in operation.

Polarization maintained optical fiber guided SLD source toghether with an integrated refernce grating scale provides highly stable differential position measurment output, perfect for a nano scale and sub-nano scale measurement and motion control applications.

NanoWave's proprietary FPGA-based signal processing core provides a high SNR (signal to noise ratio) measurement result while offering flexible adaptation for demanding customer's requests.

Application examples of SPPE-1000 System

1. Semiconductor photolithographic tools
2. HDD servo writer and head tester
3. Diamond turning machine
4. SPM (scanning probe microscopy) including AFM (Atomic Force Microscopy)
5. Piezo and other high precision stage positioning
6. High precision weight scale
7. 3D coordinate measurement machine for lens production

1.1 System Configuration

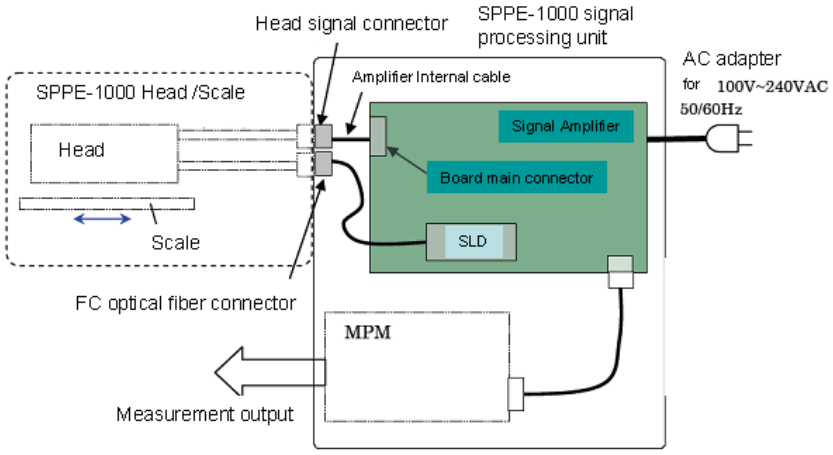

Figure 2: SPPE-1000 system photo and system diagram

Figure 2 shows a diagram of the SPPE-1000 system for a single axis measurement. The SPPE-1000 comes with two major components; one is the SPPE head and the other is the signal processing unit. The SPPE head is constructed from a rugged stainless steel body with high body stiffness. The signal processing unit contains the Super Luminescent Diode (SLD) light source and its driver, an intermediate signal amplifier and the FPGA digital signal processing board (MPM).

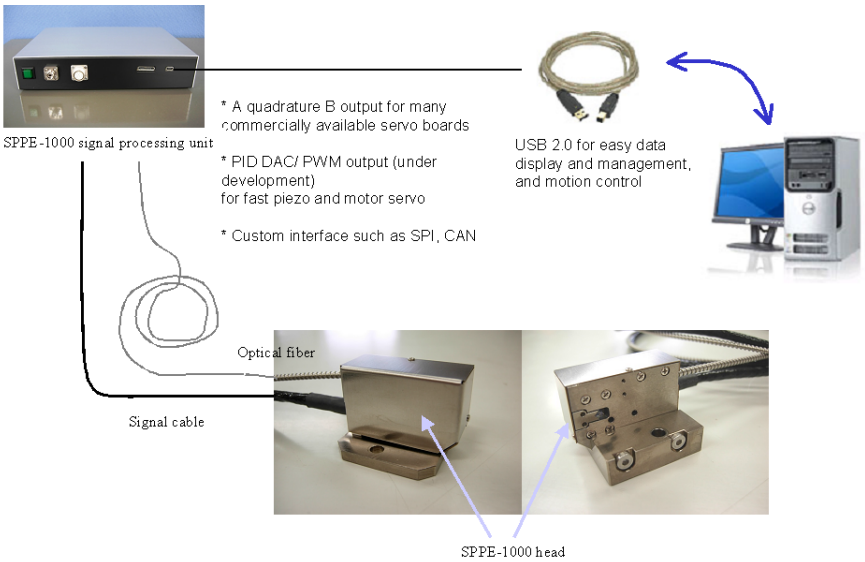

Figure 3: SPPE System Configuration (typical)

Figure 3 illustrates an application example using the SPPE-1000 system. The figure also shows the easy connection to a PC for data management and system diagnostic purposes, as well as the basic layout and elements of a motion control system.

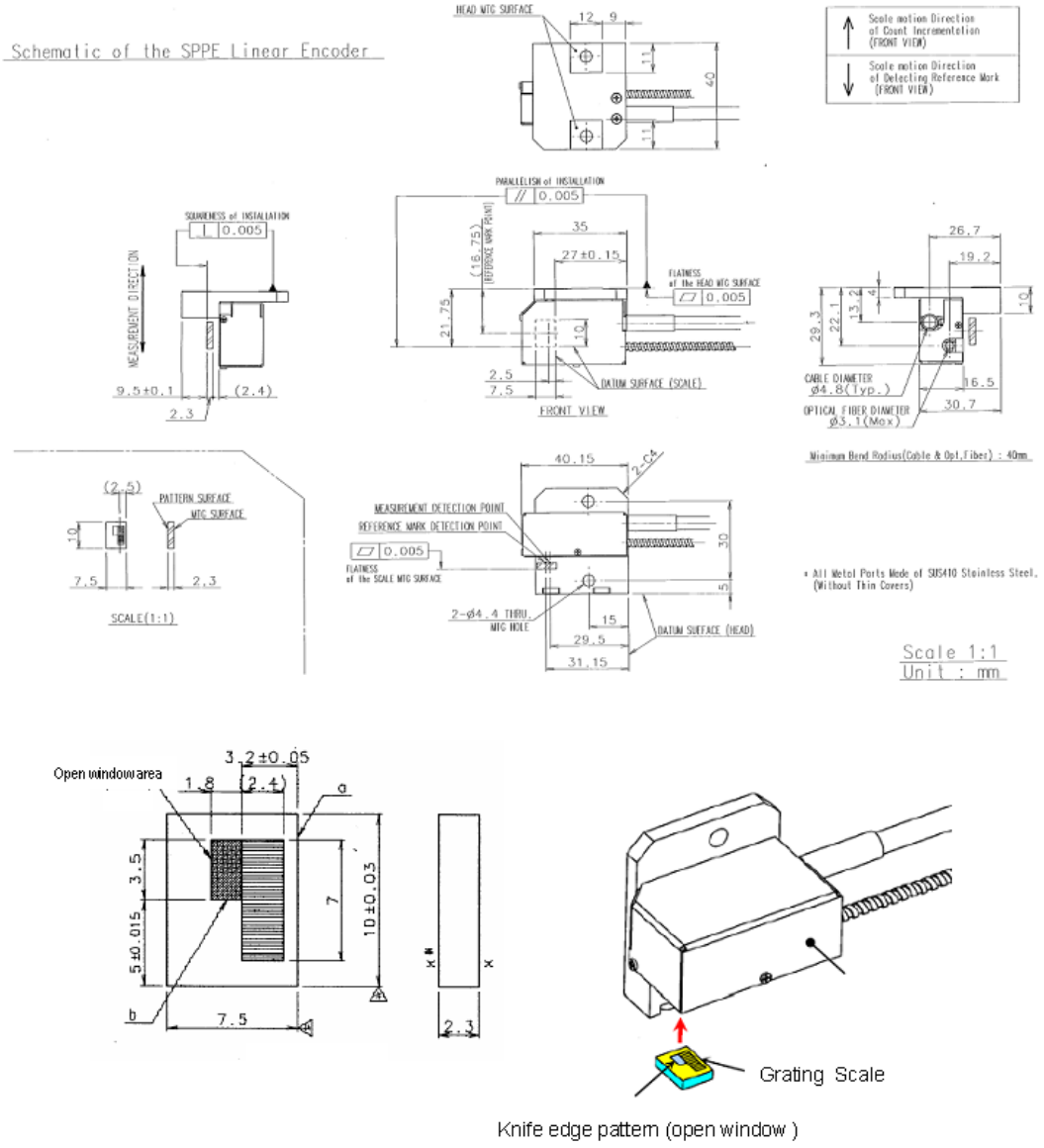

Figure 4: Mechanical dimension of SPPE head

Figure 4 shows mechanical dimensions of the glass scale and the SPPE head. It also illustrates the relationship between the SPPE head and the glass scale for the correct physical orientation. (Please note that the direction of the scale is important for correct operation of the SPPE system.) The glass scale comes with a zero index mark, which is based on a knife edge pattern. The triangular marks shown in the glass scale dimension indicate the datum planes for attaching the scale to a support structure.

Additional glass scales at the same or different dimensions will be available to SPPE customers as spare parts. Please contact NanoWave for pricing and availability.

1.2 SPPE-1000 Head and Scale Specification

SPPE-1000 HEAD AND SCALE SPECIFICATION TABLE		
SPECIFICATIONS		NOTE
Minimum resolution	7.6pm	
Maximum speed	400 mm/sec	
Travel range	3mm	Consult NanoWave for different scale length
Bandwidth	3KHz	Small signal bandwidth (Higher bandwidth available)
Interpolation error	± 10nm	
Scale factor	± 10nm / ± 100μm	
Repeatability (3σ)	10nm	
Zero index position repeatability (3σ)	10nm	
Stability	± 1nm	Room temperature at 20 ± 0.01 degree C
PHYSICAL CHARACTERISTICS		
Scale signal pitch	2μm	
Light source	SLD (830nm)	Class 1 (Class 3R if the head cover is open.)
Head weight	215g (typ.)	
Scale weight	5g (typ.)	
θ_x	± 0.44mrad	See Figure 5
θ_y	± 1.45mrad	See Figure 5
θ_z	± 1.45mrad	See Figure 5
Operating gap distance	2.4 ± 0.1mm	See Figure 4
CABLE/ OPTICAL FIBER		
Optical fiber length	1.25m	See Figure 6
Optical fiber diameter	ϕ 2.9 ±0.2 mm	Stainless tube diameter, FC connector
Min. optical fiber radius of curvature	R40	
Signal cable length	1.25m	See Figure 6
Signal cable diameter	ϕ 5.1 mm (Typ.)	See Figure 6

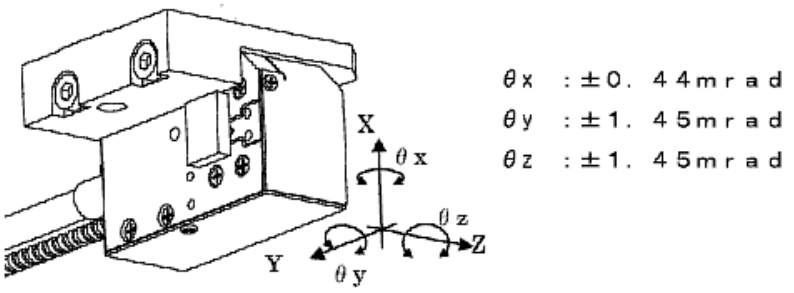

Figure 5: Definition of the SPPE head coordinate

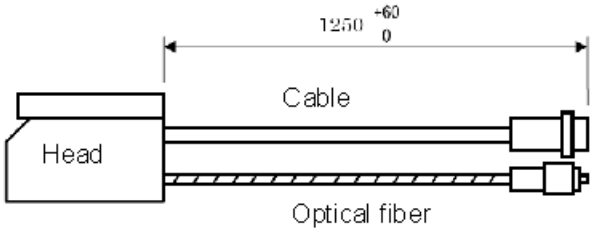

Figure 6: Length of the SPPE cables

1.3 Serial Number Location

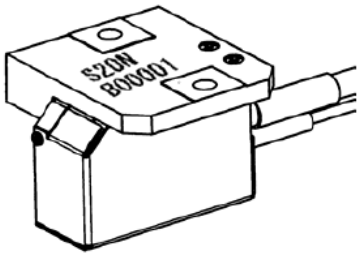

Figure 7: SPPE head serial number location

Serial number can be found under the SPPE head as shown in Figure **??**.

1.4 RoHS Compliance

SPPE-1000 head and signal processing unit comply with the RoHs standard.

1.5 Environmental Condition

Environmental Condition		
Item	During operation	During storage
Temperature	23 ± 10 degree C	-20 ˜ 60 degree C
Humidity	< 95% RH (no condensation)	0 ˜ 40 degree C, < 95% RH
	(no condensation)	40 ˜ 60 degree C, < 80% RH

- Induced noise immunity
  No miscount occurs after applying ± 1KV (pulse width 50nsec/1usec)

2 Overview of SPPE-1000 Signal Processing Unit

2.1 Specification

NanoWave implements the proprietary DSP (Digital Signal Processor) technology which is based on a custom-designed digital FPGA (Field Programmable Gate Array). This patented approach provides high-bandwidth, high-precision and real-time processing, often not obtainable with conventional digital signal processors. The core functions of the position encoder are implemented in a high-speed and high-density FPGA which provides unprecedented flexibility to support future design changes, algorithm improvements, customization, and or revision updates.

SPPE-1000 SIGNAL PROCESSING UNIT SPECIFICATION TABLE		
SPECIFICATIONS		NOTE
Measurement axis	1	
Power supply	Single phase 100 ~ 240VAC	
Power consumption	100 VAC : 10VA	
	200VAC : 10VA	Green light is on during the power-on
Minimum resolution	7.6pm	
Measurement range	40bit	Maximum 8.3m
Maximum sampling rate	40MHz	Synchronous with the main FPGA clock
DAC output	12bit 40MSPS	1.6 ± 1V
PC interface	USB 2.0	Base GUI is provided
ABOSOLUTE MAXIMUM RATING		
Power supply	90V ~ 264VAC (47 ~ 63Hz)	
Output voltage	-5.5V ~ +5.5V	
Ambient temperature	23 ± 10 degree C	
Storage temperature	-20 ~ +60 degree C	

2.2 Mechanical Dimension of the Signal Processing Unit

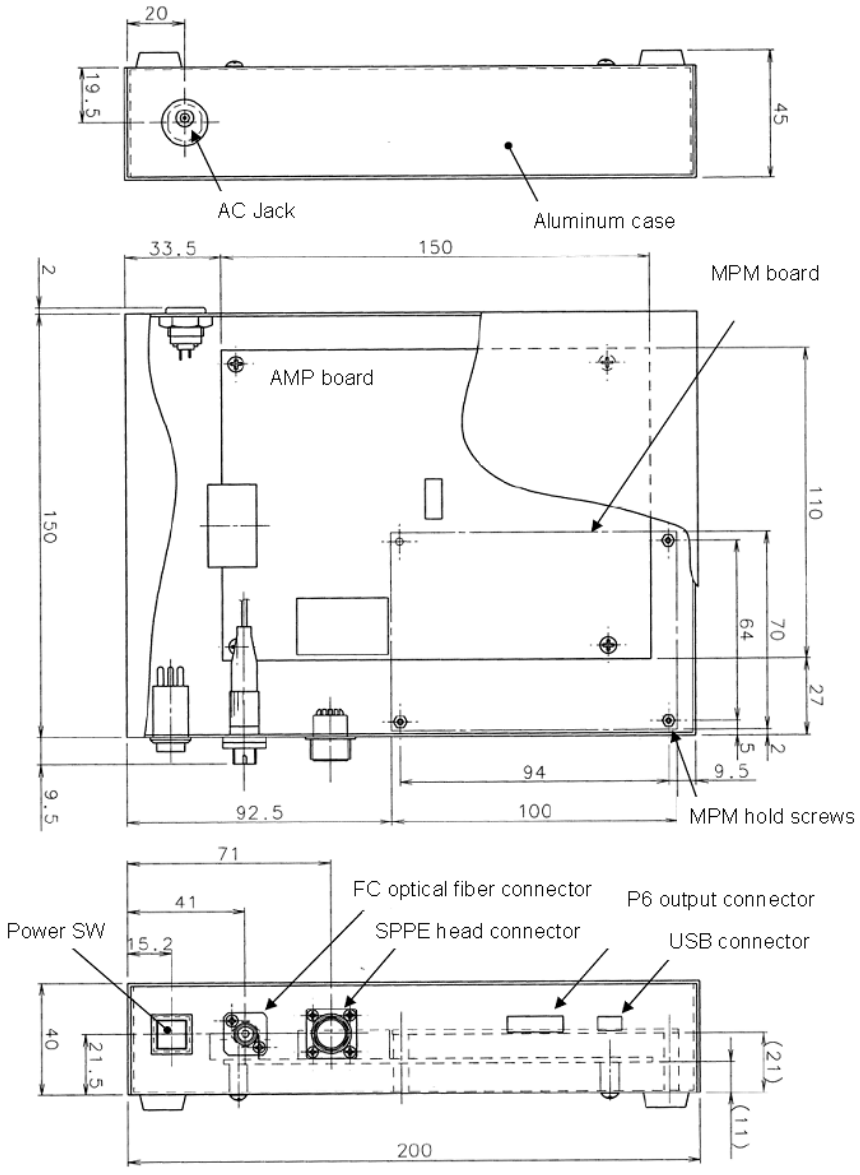

Figure 8: SPPE-1000 signal processing unit

Note: The mechanical drawing is not meant for user modification. Please do not open the box without a prior written consent from NanoWave, Inc.

2.3 Pin Assignment for the User Input/Output Connector

The connector P6 (shown in Figure 8) is offered as a user Input/Output connector. (User must purchase the mating connector since it is not included in our standard package.) A 24-pin connector (ST60-24P, Hirose) is used to output A-quad-B digital signals, PWM, and Delta-Sigma DAC signals. An external sampling clock can also be input through the connector. See Table below for the default pin assignment. They are designed for 3.3V logic in general, however 5V logic compatible.

Pin assignment for the P6 connector			
Pin	Function	Specifications	I/O
1	General purpose I/O	Single end	I/O
2	GNDA		
3	General purpose I/O	Single end	I/O
4	GNDA		
5	GNDD		
6	Global clock		I/O
7	GNDD		
8	VCC3V3		
9	+A (A quad B)	A quad B output (A positive)	O
10	-A (A quad B)	A quad B output (A negative)	O
11	+B (A quad B)	A quad B output (B positive)	O
12	-B (A quad B)	A quad B output (B negative)	O
13	$DAC1_P$	1 bit Delta-Sigma DAC	O
14	$DAC1_N$	1 bit Delta-Sigma DAC	O
15	+Z	Index Pulse	O
16	-Z	Index Pulse	O
17	+General purpose I/O	Differential pair	O
18	-General purpose I/O	Differential pair	O
19	VCCA5		
20	GNDA		
21	$+EXSPCLK$	External Sampling Clock Input	I
22	General purpose I/O	Single end	I/O
23	General purpose I/O	Single end	I/O
24	General purpose I/O	Single end	I/O

Figure 9 shows the mating connector, ST-40X-24S available from Hirose.

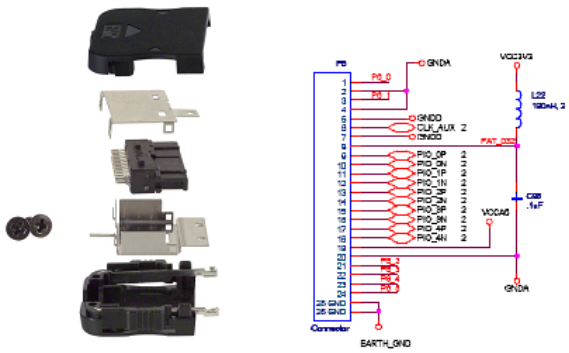

Figure 9: Photo of ST-40X-24S, mating connector for ST60-24P (0.5mm pitch connector)

2.4 A Quadrature B Output

The SPPE-1000 provides two digital differential output signals termed A and B which are used to indicate travel direction and speed. The phase of the A signal will lead the phase of the B signal by 90 degrees when the stage moves in the positive direction (see Figure 10). A separate digital differential output signal termed Z (index) is used to indicate zero or home position.

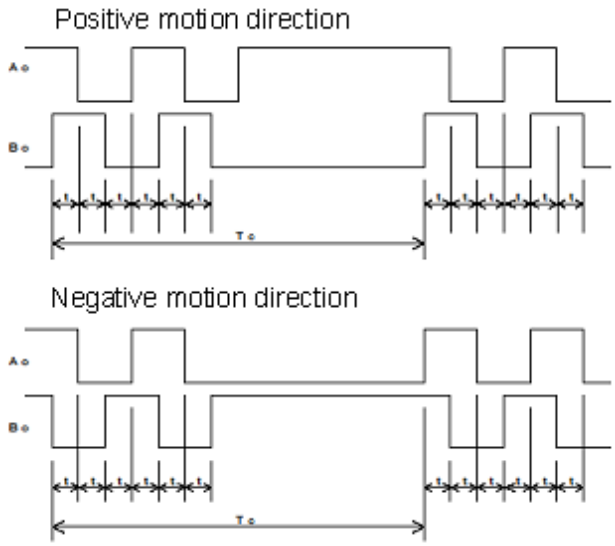

Figure 10: A/B Phase output format

Due to the extremely high-resolution capability of the SPPE position encoder, NanoWave is also working on a more advanced serial communication interface. The specifications will be released in the near future.

3 CP3000 Overview

CP3000 allows users to monitor and save data generated by the SPPE-1000 hardware. Users can select up to 11 variables being monitored through the MPM hardware inside the SPPE-1000 signal processing unit. Data can also be saved as comma separated values (.csv) and subsequently be loaded into or from other applications such as Microsoft Excel and Matlab (available from respective vendors).

More than one SPPE-1000 system can be connected to a single PC at a time. The CP3000 software allows users to select which system they would like to monitor.

The latest version is currently available as a free download from NanoWave's website (www.nanowave.com). Help manuals can also be obtained for the CP3000 software through the Help menu or by pressing F1 when the software is in focus.

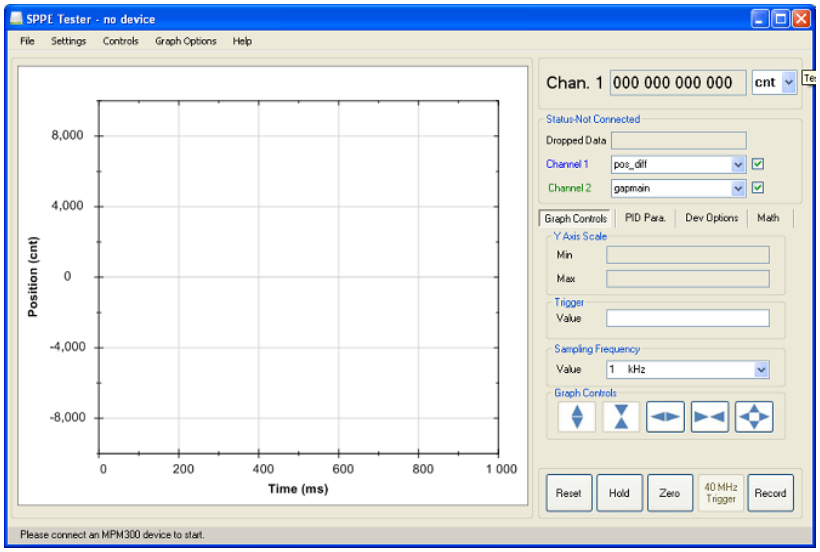

Figure 11: CP3000 User Interface

Features of CP3000 User Interface Software

1. Digital oscilloscope like PC application for monitoring position, velocity and other internal register status.
2. Simultaneous selectable dual channel input data.
3. Third channel data provides the result of math operation between the two data channels.
4. Up to 20 kHz continuous sampling and 40MHz manual sampling.
5. Monitor input data and trigger alarms when upper or lower limits exceeded.
6. Simple storing and retrieving of waveform data.
7. Save continuous input data as a text file that can be imported into other applications such as Matlab and Excel.
8. Hardwired PID motion controller and development environment (option).

9. Control and monitor multiple SPPE-1000 from one software application.
10. Quick installation and setup for Windows XP/2000/Vista Operating Systems.

3.1 Graph Controls

CP3000 provides a graph for visualizing trend-data from the SPPE-1000 system. The five buttons shown in Figure 12 encompasses the basic graph functions particularly, zoom-out y-axis, zoom-in y-axis, zoom-out x-axis, zoom-in x-axis, auto-scale to show all data points within the graph. The graph can be operated in

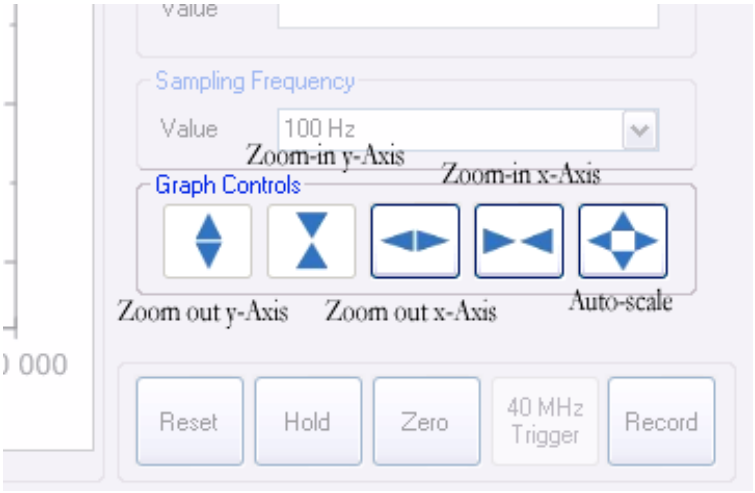

Figure 12: Basic graph control buttons.

two modes: manual and auto. In auto mode, the graph automatically adjust the y-axis to show all the point values, thus the zoom-in y-axis and zoom-out y-axis button will be disabled during this mode. The graph mode can be set from 'Graph Options' pulldown menu in the menu bar. Other available functions include increasing and decreasing graph-center offset, clearing the graph and holding the graph.

3.2 Sampling Rate

NanoWave's CP3000 software provides continuous sampling rates of up to 20 KHz. User can also select 40 MHz manual or 40 MHz periodic where each frame (whole graph area) is sampled at 40 MHz.

For 40 MHz manual, users can trigger the sampling by pressing the trigger button. Alternatively, 40 MHz periodic will force the CP3000 software to sample at 40 MHz every 3 seconds.

3.3 Math Functionality

Simple mathematical functions such as $Channel1 - Channel2$, $Channel1 + Channel2$, root mean square (RMS), and upper limits and lower limits alarm (for Channel 1) is provided in CP3000 software. For customized functionality such as FFT, please contact NanoWave.

3.4 PID Functionality

SPPE system also comes with MPM (motion processing module) hardware which provides PID functionality. Users can specify PID parameters such as P-Coefficient, I-Coefficient, D-Coefficient, D-Interval, I-Saturation

and Target, all through the CP3000 software.

Currently, NanoWave does not guarantee the stability nor provide technical support for the PID functionality although users are encouraged to try it.

4 NanoWave Programming Library Overview

In addition to the complete support within CP3000, MPM hardware is also supported through a provided *C#* class library. The library is available to Windows programmers to interface their own software to NanoWave's MPM hardware.

The library can also be wrapped and called from programs such as National Instrument's Labview.

4.1 Functions summary

Below is a summary of the functions provided by the Class Library.

USB_Transaction()
Constructor, creates the object.

void Initialize()
Must be called to initialize parameters after creating the constructor and assigning event handlers.

int GetMPMDeviceCount()
Get the number of compatible MPM hardware connected to the host machine.

long[] GetData()
Gets data for all 3 channels. SetChannel$n$ can be called to change the input data type. An array of long (Int64) containing 50 points of data for each channel. The 50 points for each channel are sampled at 20 KHz. The data is organized as shown in Figure 13. From index 0 to index 49, the array contains the data for Channel 1, from index 50 to index 99, the array contains the data for Channel 2, while Channel 3 data is from index 100 to index 149 in the array.

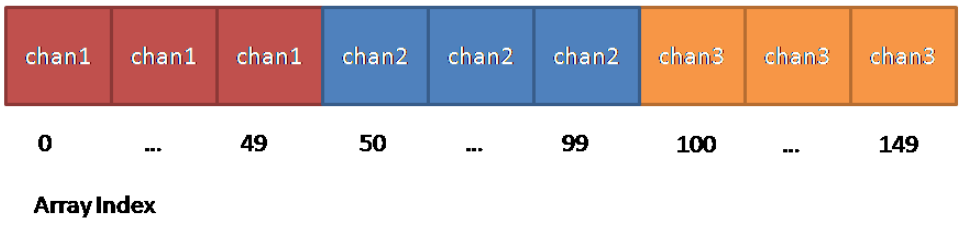

Figure 13: The 3 channel data is interleaved in the array of long returned when calling GetData() function.

short GetFirmwareVersion()
Gets the MPM firmware version. GetData() function must be called at least once before getting the firmware version.

void UpdateOutData()
Resend all parameters (such as PID parameters, cutoff frequency) to MPM hardware, particularly after resetting MPM hardware.

void TransferInDummytData(int n)
Transfers dummy data to clear the USB bus if data corruption is detected.

void SelectDevice(int index)
If multiple MPM hardware are connected to one host machine, switch to the specified 'index' MPM device.

float GetDropRatio()
Gets dropped packet rate.

void Trigger40MHzSampling()
Gets data from MPM hardware at 40 MHz sampling rate.

void SetChannel1(int type)
Select the data type for Channel 1. The type correspond to the list below:

0. Position
1. Index Position
2. Gap Distance
3. ADC2 (Main Signal)
4. ADC3 (Reference Signal)
5. adc1
6. freq_quartz
7. gapaux
8. phase_diff
9. posmain2
10. posaux2
11. sine10

void SetChannel2(int type)
Selects the data type for Channel 2. See SetChannel1 for the corresponding data type.

void SetChannel3(int type)
Selects the data type for Channel 3.

1. Chan 1 - Chan 2
2. Chan 1 + Chan 2

void Zero()
Sets the current position as zero.

void EnableExternalSampling(bool en)
Enable external sampling signal (Please see Pin Assignment for the User Input/Output Connector for more information).

void EnableIndexPulse(bool en)
Enable Z-Index pulse to reset the current position to 0.

void SetCutOffFrequency(int val)
Sets the cutoff frequency. The *val* corresponds to the list of frequency below.

0. 3 KHz
1. 777 Hz
2. 97 Hz
3. 24 Hz

void Reset()
Resets MPM hardware.

void SetPID_Coeffients(short P_coeff, short I_coeff, short D_coeff, long Reference, int I_Saturation, short D_Interval)
Hardware detection and removal, transferring data, and sending control packets

public event DeviceFound Event triggered when a MPM family device is connected to or removed from a host PC.

5 Example Application

An example application with source code is provided after installing NanoWave's SPPE Supplementary Software package. The examples will be in C:/Program Files/NanoWave/SPPE/Examples unless specified otherwise by the user during installation.

The provided C# Example Application can be recompiled using Visual Studio package or Visual Studio Express. LabView example application will require National Instrument Labview Software.

6 Installing SPPE-1000

6.1 Mechanical Assembly Procedure for SPPE Head

Important !

- Always wear electro-static dissipation glove before head-scale assembly
- Do not touch the sensor window nor glass scale surface, especially in grating area

M4 hex screws are to be used for securing the SPPE head in position. The recommended screw length would be 10mm and 16mm based on the side respectively. (They are not included in the delivered package.) Tightening torque should be less than 1.2Nm. If necessary, apply anti-loosening counter-measure.

The head position can be accurately obtained simply by butting the datum surface of the head to a well-defined position pins or surfaces.

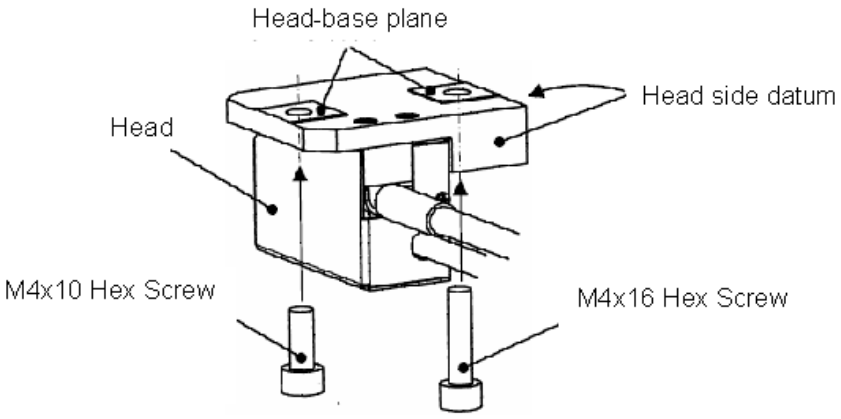

Figure 14: How to secure the SPPE Head position

The gap distance between the head and the glass scale should be set at 2.4mm ± 0.1mm. (refer to Figure 4)

6.2 Sub-Assembly Procedure for the Glass Scale

A recommended procedure

1. Clean the surface being glued with alcohol.
2. Apply 3M Scotch-Weld Epoxy Adhesive, DP-460-EG onto the mechanical support structure very thinly and evenly.
3. Place the glass scale after checking its orientation (refer to Figure 4 onto the support structure by applying a light force on the non-grating area of the scale using cotton swabs.
4. Cure the glue for more then 24 hours while holding the scale position at room temperature.

Important note for scale sub-assembly

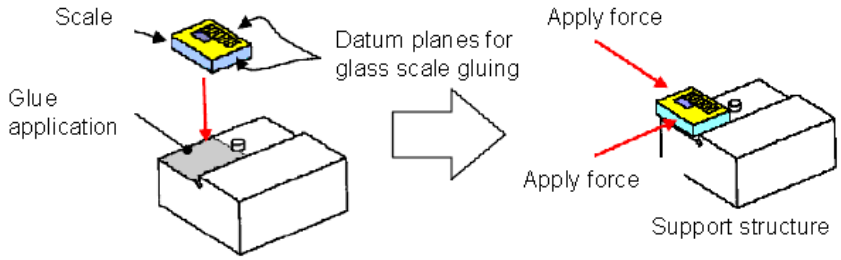

Figure 15: How to prepare the glass scale fixture

- Glass scale is made of a fused quartz; therefore choose a support structure material with a matching thermal expansion coefficient.
- Glass scale has to be set in the correct direction relative to the SPPE head orientation. The measurement side is always on the first surface of the grating scale. The scale position can be accurately obtained simply by butting the datum surface of the scale to well-defined position pins or surfaces of the support structure.
- Once the glue is set, it should be left for at least 24 hours under room temperature before any further use. Do not touch the surface of the glass scale since finger prints or minute scratching on the grating could cause malfunction. Any tiny bump on the surface of the support structure should be filed away by oil stone before applying the glue.
- One of the keys to obtaining a stable measurement results is to apply the glue as evenly and thinly as possible. Annealing the material would be recommended if the support structure will go through any significant machining job prior to the glue application.

7 SPPE Supplementary Software Package Installation

The SPPE system comes with NanoWave's proprietary software package and programming library. The software package is currently only available for Windows-based Operating Systems (except Windows CE and Windows Mobile).

The NanoWave Supplementary Software Package installer will install the following:

1. CP3000
   Please see the CP3000 Software Overview section in this document.
2. MPM.dll
   MPM.dll is the main library which users will be calling from when writing their software. Please see the NanoWave Programming Library Overview for more information on the available functions. For LabVIEW-implemented software, please put this file in the same folder as the VI calling the MPM.dll library. Typically, *CyUSB.dll* and *firmware.hex* will also need to be in the same folder.
3. CyUSB.dll
   CyUSB.dll is Cypress's base library for Cypress-based USB chip. This file is required for the *MPM.dll* to work correctly. For LabVIEW-implemented software, please put this file in the same folder as the VI calling the *MPM.dll* library.
4. firmware.hex
   firmware.hex is required for any MPM300-related software to recognize the MPM300 hardware connected to the PC. Please put this file in the root folder of the program.

5. C# example program
   This example program will require Visual Studio to recompile. Visual C# Express can be obtained from $http://www.microsoft.com/express/vcsharp/$ for free.

6. LabVIEW example program
   This example program will require National Instrument's LabVIEW program to view and edit. The example program will show how to get data from the MPM300 hardware through the USB interface.

User can start CP3000 the program from Program Menu or the shortcut on the desktop. The compiled binaries, *MPM.dll*, *CyUSB.dll* and *firmware.hex*, is typically located in $C:ProgramFiles/NanoWaveInc/bin$ while the C# and LabVIEW example program is in $C:ProgramFiles/NanoWaveInc/Examples$, unless specified otherwise during the installation of the supplementary software package.

The supplementary software package can also be obtained at http://www.nanowave.com

Please contact NanoWave for customized software packages.

8 Troubleshooting

8.1 The Principle of SPPE Technology

Before we discuss trouble shooting in detail, we will first provide an overview of the principle of SPPE technology. This section is in general for advanced users; in many cases, the factory-shipped conditions are sufficient for sub-nanometer precision measurement without any user re-adjustment.

While it is relatively easy to set up the SPPE-1000 system for extreme high precision position measurement, please keep in mind that many pre-cautions specific to sub-nanometer position sensing must be applied.

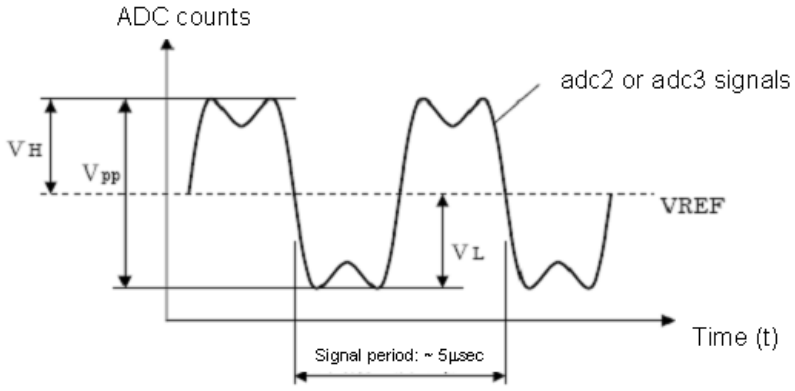

Figure 16: SPPE Signals

Scanning Probe Position Encoders (SPPEs) are, in some ways, similar to other non-contact, reflection-based, optical encoders. Laser light is projected onto a diffraction grating used as a measuring scale. The reflected light is collected in the encoder head and converted via a photo diode cell into one or more electrical signals for further processing.

The most important principle of an SPPE is that the laser light is oscillated rapidly (i.e., scanned) with very small amplitude on the grating scale. The direction of the scanning is the same as the direction of the measurement of interest. This creates a high-frequency modulated signal, even when there is no motion as

indicated in Figure 16. When motion does occur this modulated signal undergoes phase shifts and changes in shape.

After Analog-to-Digital conversion (at a rate of 40 MHz), position information is extracted from this complex signal using NanoWave's proprietary signal processing algorithms. These algorithms are implemented in firmware in a high-speed FPGA within our SPPE products and ensure low latency and high signal bandwidth. The algorithms employ a phase-locked-loop and examine the higher harmonics and phase changes in the received signal. Therefore, SPPEs are insensitive to drifts in the light intensity and other noise sources found at lower frequencies.

8.2 Position Measurement Results

SPPE uses an identical grating structure embedded inside the head as a reference in oder to compensate for measurement drift attributed to the system design. The final result, 'Position', is thus the subtraction between the position measurement result from the main signal and the one from the internal grating.

1. Run CP3000 software and set the sampling rate to 1KHz and assign 'Position' for Channel 1 as shown in Figure 11.
2. Check the box next to the channel assignment for only the value you want to display.
3. Turn-on the SPPE-1000 signal processing unit.
4. Wait for a few seconds until 'Position' value settles.
5. Adjust the Graph controls so that the 'Position' value can be monitored on the screen.
6. Check the value on the screen to see if it would make sense or not.

There is a real-time RMS value shown in the 'math' tab. One can use this result to see what improvements in actual system set-up can help decrease the measurement noise. For example, any vibration on the floor or through the signal cables to the SPPE head, any minute strain on the optical fiber can easily change the position measurement. It is common practice that such signal cables and optical fiber are securely fastened to a stiff mechanical support structure for the optimum measurement noise.

The bandwidth of the position measurement output can be specified through the 'Settings' menu on the CP3000 software. The actual low pass filter resides inside FPGA, clocked at 40Mhz, to avoid Aliasing problem. The default setting is 24Hz.

9 Information

NanoWave's SPPE technology is patent protected. The following U.S. patents have been issued to NanoWave: 5,589,686; 5,744,799; 6,639,686 and corresponding foreign patents. In addition NanoWave has several patents pending.

For more information on products, services, prices and deliveries, please visit our website at *www.nanowave.com*. Please send questions to $info@nanowave.com$.

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