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DESIGN AND CONSTRUCTION OF THE ALTERNATIVE CONTROL SYSTEM FOR NEUTRON DIFFRACTOMETERS AND SPECTROMETERS AT PTBIN, BATAN

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ABSTRACT

DESIGN AND CONSTRUCTION OF THE ALTERNATIVE CONTROL SYSTEM FOR NEUTRON DIFFRACTOMETERS AND SPECTROMETERS AT PTBIN-BATAN. The alternative control systems based on programmable peripheral interface (PPI) IC 8255 and programmable interval timer (PIT) IC 8253 have been developed to control the neutron diffractometer and spectrometer instruments at Center of Technology for Nuclear Industrial Materials (PTBIN)-BATAN which had defective control systems. This alternative control system has been installed at *Four Circle Diffractometer/Texture Diffractometer* (FCD/TD), *High Resolution Powder Diffractometer* (HRPD) and *Triple Axis Spectrometer* (TAS). The control system components were assembled as a plug-in printed circuit board (PCB) at the ISA slot of a personal computer. IC PPI 8255 was programmed to control the mechanical movements of the instruments and IC PIT 8253 was programmed as a main counter and used as programmable monitor counter. The testing either with or without neutrons has shown that this alternative control system can be used to control the neutron diffractometers and spectrometers also the result shows that this system is in a good performance.

Key words: Alternative control system, neutron diffractometer and spectrometer, interface, monitor counter and main counter.

ABSTRAK

***RANCANG BANGUN SISTEM KENDALI ALTERNATIF UNTUK PERALATAN DIFRAKTOMETER DAN SPEKTROMETER NEUTRON DI PTBIN, BATAN**. Telah dikembangkan sistem kontrol alternatif yang berbasis pada programmable peripheral interface (PPI) IC 8255 dan programmable interval timer (PIT) IC 8253 untuk mengendalikan peralatan difraktometer dan spektrometer neutron di Pusat Teknologi Bahan Industri Nuklir (PTBIN) - BATAN yang sistem kendalinya sudah tidak berfungsi. Sistem kendali alternatif telah diterapkan pada difraktometer empat lingkaran/difraktometer tekstur (FCD/TD), difraktometer serbuk resolusi tinggi (HRPD) dan spektrometer tiga sumbu (TAS). Komponen-komponen sistem kendali dirakit pada papan rangkaian cetak (PCB) yang dipasang pada slot ISA komputer pribadi. IC PPI 8255 diprogram untuk mengendalikan gerakan mekanik peralatan dan IC PIT 8253 diprogram sebagai pencacah utama dan pencacah monitor. Hasil pengujian baik dengan neutron maupun tanpa neutron menunjukkan* *bahwa sistem kendali alternatif dapat digunakan dan berfungsi dengan baik untuk mengendalikan difraktometer dan spektrometer neutron.*

Kata Kunci: *Sistem kendali Alternatif, difraktometer dan spektrometer neutron, antarmuka, pencacah monitor dan pencacah utama.*

INTRODUCTION

Neutron Scattering Laboratory of PTBIN-BATAN at Serpong is equipped with seven research instruments using neutron scattering techniques. They are a Neutron Diffractometer for Residual Stress Measurement (RSM), a Four Circle Neutron Diffractometer / Texture Diffractometer (FCD/TD), a High Resolution Neutron Powder Diffractometer (HRPD), a Triple Axis Spectrometer (TAS), a Small Angle Neutron Scattering (SANS) Spectrometer, a High Resolution Small Angle Neutron Scattering (HRSANS) Spectrometer and a Neutron Radiography Facility (NRF). All instruments, except the RSM diffractometer were installed in 1992, under BATAN's Phase III Project. RSM diffractometer was installed in 1987 and it was a Grant from the *Japan International Cooperation Agency* (JICA). All spectrometers and diffractometers are controlled by personal computer (PC) using a specific control system [1-3]. As time goes by the computer controlling each instrument became out of order and the control system was defective. At first TAS computer was out of order in 1996, and followed by FCD/TD in 1998 [4], and the next was HRSANS in 2000 [5]. HRPD had a similar problem in the year 2001 and followed by SANS in 2003. Due to lack of information about the controller (black box) the author had many difficulties to repair or replace the computer. In order to solve the problem the author worked very hard to develop a design and construction of the controller for each instrument and replace the existing computer. In the year of 1999 we work together with a lecturer from Bandung Institute of Technology (ITB) to start designing an alternative control system for FCD/TD. In 2000 we began to construct the controller using PIC16F84 microcontroller for FCD/TD [6]. The controller was connected to a personal computer via RS-232 serial port. Using this alternative controller, FCD/TD can be handled although there was some problem occurred during the experiment. It took a long time to get the data from one sample. To solve the problem, in the year 2001 the author started to design and construct a new control system based on Programmable Peripheral Interface (PPI) 8255 and Programmable Interval Timer (PIT) 8253 which was connected to a PC via ISA slot [7]. Using this control system the performance of FCD/TD was found better than that using the controller based on microcontroller PIC16F84 [8].

In the year 2002 the author started to build a controller for HRPD which has 32 main detectors moved on dance floor using air cushion system within 2 years. At the end of the first year the HRPD can be operated but the movement of θ and 2θ angles were not perfect [9]. In the second year the controller of the HRPD was connected to both of θ and 2θ absolute encoders. The accuracy of θ and 2θ angles can reach (0.01°) [10].

In the year 2004 the construction of TAS control system was completed. It was found that TAS controller was more complicated than HRPD or FCD/TD controller, because TAS has 18 stepper motors and uses air cushion system [11].

In principally this alternative control system can be used to control the X-Ray diffractometer as well or other instrument which uses stepper motor and counting system.

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BASIC DESIGN

The main components of alternative control system are Programmable Peripheral Interface (PPI) 8255 and Programmable Interval Timer (PIT) 8253. PPI 8255 was used as an input/output and PIT 8253 was used as a programmable counter. The PPI 8255 and PIT 8253 were chosen because both ICs were available in the market, inexpensive and have a good stability.

● IC Programmable Peripheral Interface (PPI) 8255

PPI 8255 has three ports named Port A, port B and port C. Each of port A and B has eight pins and can be programmed as an input or output. Port C has four bits Lower and four bits Upper and each (four bits) can be programmed as an input or output, for example, four bit as an input and four bit as an output or all eight bits as an input or output. The selection of input/output is chosen by the control register of the PPI 8255. This control register has eight bits which are divided into group B (bit 0-2), group A (bit 3- 6) and 1 *set flag* (bit 7) as shown in Figure 1 [12]. Addressing of each port and control register was done by pin A_0 and A_1 of the IC as described in Table 1.

Table 1. Addressing and basic operation of each port on PPI 8255.

A_1	A_0	$\overline{RD}$	$\overline{WR}$	$\overline{CS}$	INPUT OPERATION (READ)
0	0	0	1	0	Port A → Data Bus
0	1	0	1	0	Port B → Data Bus
1	0	0	1	0	Port C → Data Bus
					OUTPUT OPERATION (WRITE)
0	0	1	0	0	Data Bus → Port A
0	1	1	0	0	Data Bus → Port B
1	0	1	0	0	Data Bus → Port C
1	1	1	0	0	Data Bus → Register control

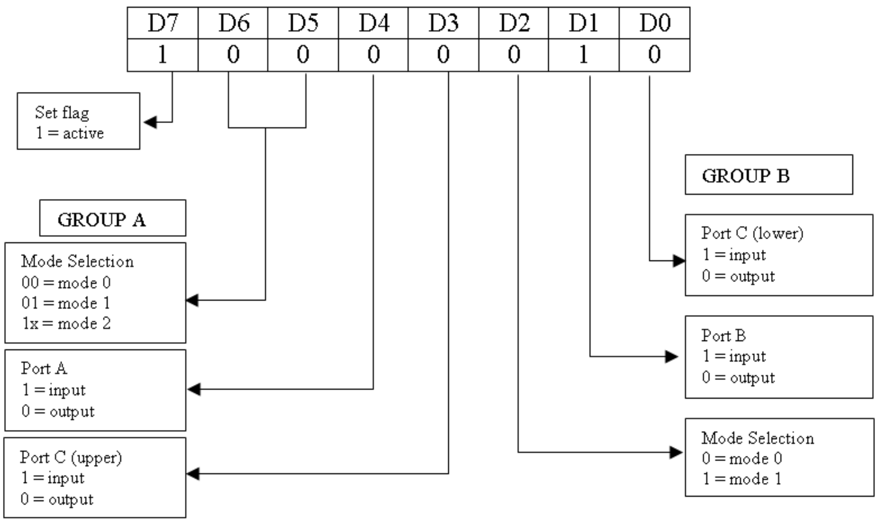

Figure. 1. Procedure to fill the 8 bit control register PPI 8255

Figure 1 shows that the control register is filled by 1000 0010 input in binary or 82 in hexadecimal. It means that port A and port C we used as an output and port B as an input. The output ports are used to turn on the stepper motors through the circuit driver and to activate the air cushion system. The input ports are used to read the axis positions (limit switches).

● IC Programmable Interval Timer (PIT) 8253

IC Programmable Interval Timer (PIT) 8253 has 3 independent countdown counters called counter 0, counter 1 and counter 2 . Each counter can be programmed either as a counter, timer or frequency divider, depending on the content of its control register. The procedures to fill the control register are shown in Figure 2 [12]. Counter 0 is used as a divider, counter 1 as a monitor counter/timer and counter 2 as a main counter.

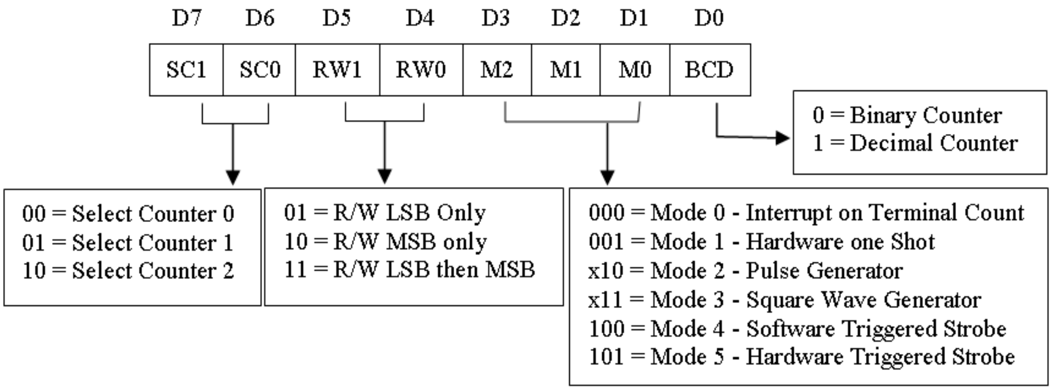

Figure. 2. Procedure to fill the control register PIT 8253

● Addressing interface card

Interface cards were installed on ISA slot of the personal computer. To communicate with the computer, the interface card should have specific addresses. There are many address ports available on the mother board (A_0 – A_{19}). We use only 10 address ports (A_0 – A_9), from 10 ports we have 2^{10} = 1024 addresses and can be grouped into two groups:

- 256 addresses from (0000) h – (00FF) h are used by the computer board system.
- 768 addresses from (0100) h- (03FF) h are used by the card slot.

Usually the addresses from (100) h – (1FF) h are used for the additional I/O [12]. In designing the interface card, the author chose the addresses from (1F0) h - (1FF) h. The consideration of choosing this address is that the hardware of the interface will be simple and will use fewer components as shown in Figure 3.

The address port A_0 and A_1 were used to select each port(A,B,C) and control register of the PPI 8255 or each counter (C_0, C_1, C_2) and control register PIT 8253. The address port A_2 and A_3 were used to select the programmable IC (PPI 8255 or PIT 8253). Address port A_4-A_9 were used to activate 10 inputs of the IC NAND gate (IC 7430), so that the IC decoder 74139 and IC line driver 74245 were activated.

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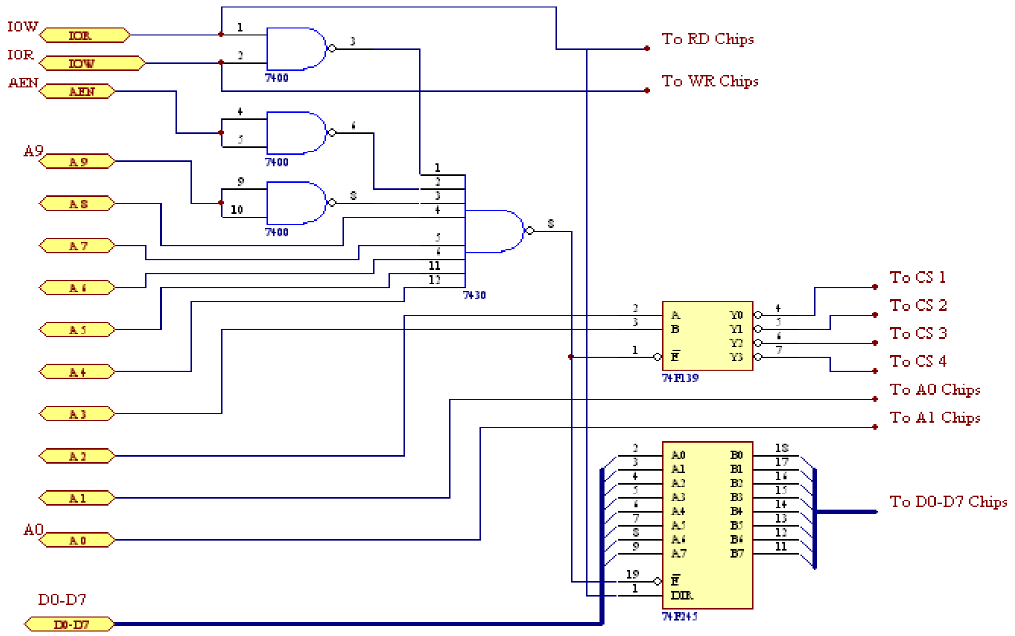

Figure 3. Addressing of interface circuit diagram

• Control system of FCD/TD

The block diagram of the FCD/TD instrument is shown in Figure 4 [13].

FCD/TD has nine stepper motors but only 5 motors are activated (ω, θ, 2θ, φ and ψ). The other four motors were not used in the mean time.

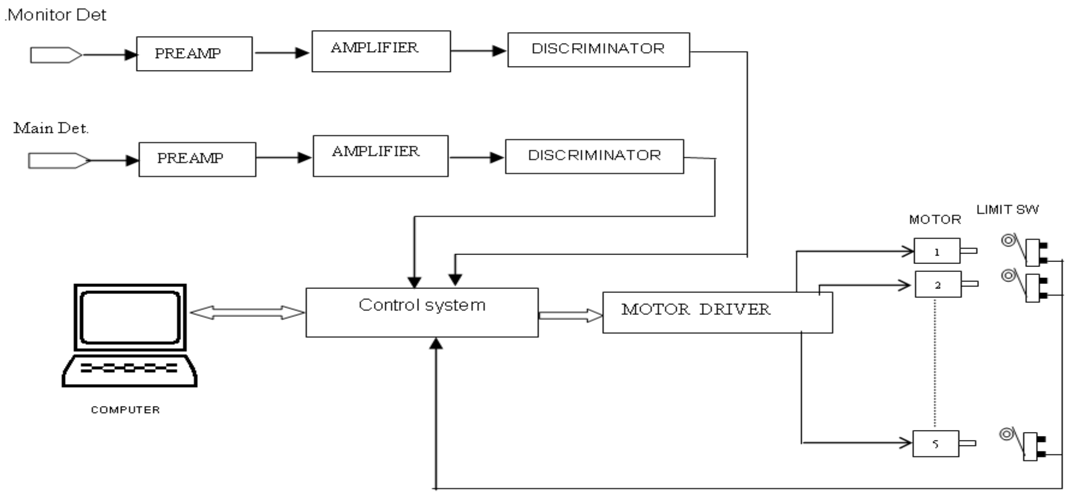

Figure 4. Block diagram of FCD/TD controller and counting system

- **Monitor Counter**

When the input of the monitor counter is connected to the frequency generator it is called preset time, and if connected to the output of monitor discriminator it called preset count. Preset time is used when neutron flux of the reactor is stable and if the neutron flux is not stable it is preferable to use preset count.

- **Main Counter**

As we know that all of the counters on the IC 8253 are countdown counters, so the counting of the counters can not be read directly. Before start counting we have to fill the counter with this number : 65536, then start and stop counting and read the counter. The result of the counting is 65536 minus the number contained in the counter.

- **Control system of HRPD**

HRPD has six stepper motors, 32 main counters and is equipped with the air cushion to lift the table of main detector shielding. The block diagram of the HRPD control system is shown in Figure 5 and in Figure 6 including the counting system [9]. To build 32 main counters, one monitor counter and one frequency divider, the controller uses 12 pieces of PIT 8253.

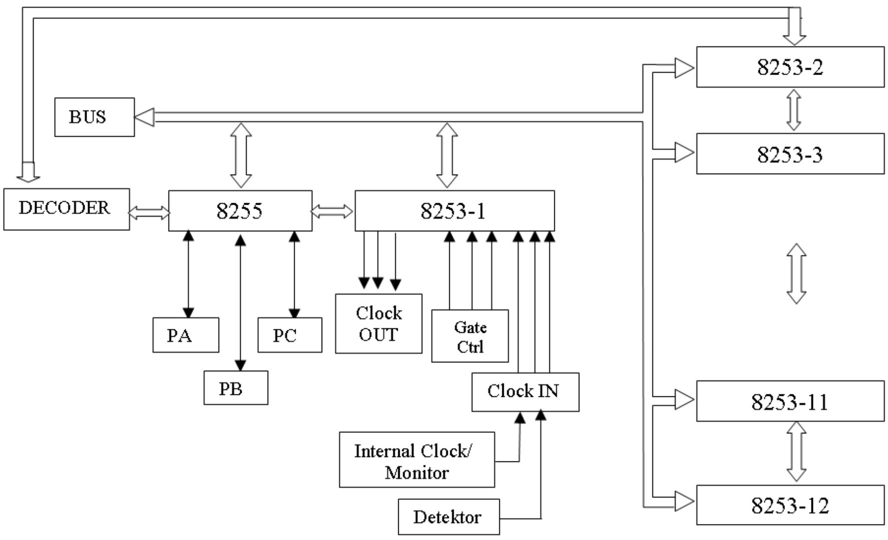

Figure 5. Block diagram of HRPD control system

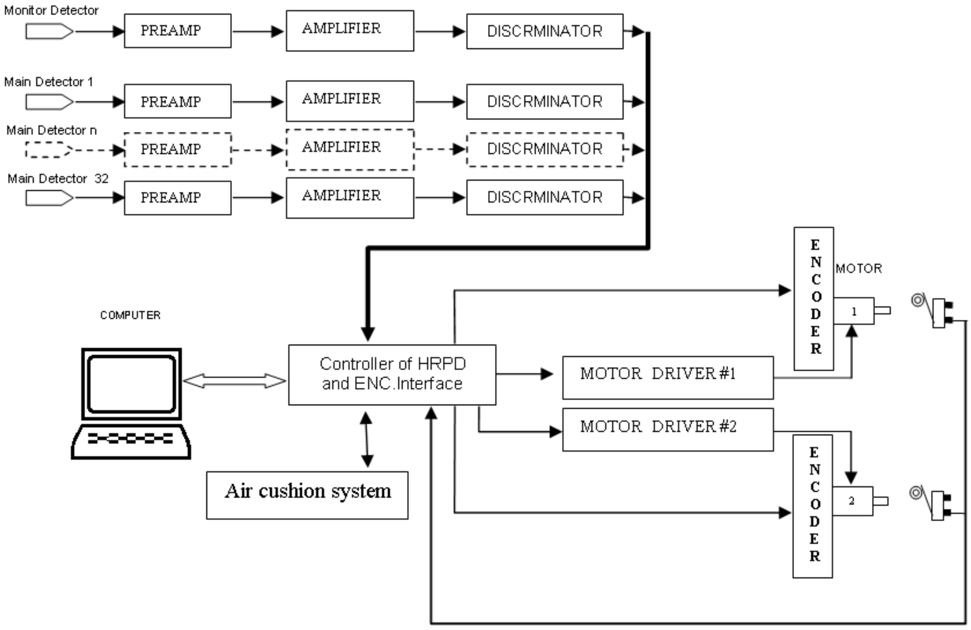

Figure 6. Block diagram of HRPD controller and counting system

● TAS control system

Triple Axis Spectrometer (TAS) has 18 stepper motors and movements of the sample table axis, analyzer and detector tables were supported by air cushion system.

The TAS control system uses two pieces of PPI 8255 and one PIT 8253. Block diagram of TAS control system is shown in Figure 7 [11].

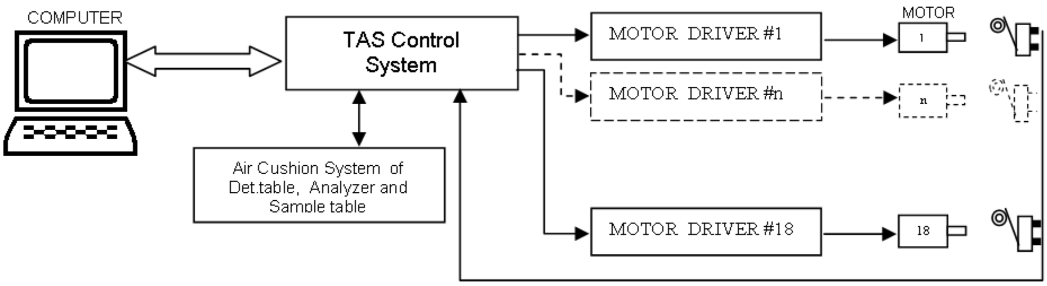

Figure 7. Block diagram of TAS control system.

Port A1, Port C1 upper, Port A2 and Port C2 upper are used as an output to activate the air cushion system and to turn on the stepper motors.

Port B1, C1 lower, B2 and C2 lower as an input to read the limit switches of the axis and feed back from the air cushion system as shown in Table 2.

Table 2. Occupation of each port of TAS control system.

LABEL	BIT / DIGIT							
	7	6	5	4	3	2	1	0
PORTA1	Ys	RXa	2θa	θa	ωa	2θs	θs	Direction
PORTB1	-	LS.RYa	LS.RXa	LS.2θa	LS.θa	LS.ωa	LS.2θs	LS.θs
PORTC1	B.U.3	B.U. 2	B.U.1	PC/PT	LS.BU3	LS.BU2	LS.BU1	Out PC
PORTA2	Xm	RXm	Cm	ω1	Xs	RYs	RXs	Direction
PORTB2	-	LS. Xm	LS.RXm	LS.Cm	LS.ω1	LS.Xs	LS.RYs	LS.RXs
PORTC2	θm	ω2	Ym	RYa	-	LS.θm	LS.ω2	LS.Ym

RESULTS AND DISCUSSION

● Test Result of FCD/TD Controller

Testing of the monitor counter

Testing was done on the counter 1 which was used as a preset time by filling the counter 1 with various numbers, to obtain different time intervals from the timer (counter 1). The result can be seen in Table 3 and Figure 8 [13]. It can be seen in Figure 8 that the time interval is proportional to 8 bit of most significant bit (MSB) counter 1.

Table 3. Testing of counter 1

8 bit MSB	Time interval [second] : 1	2	3	Average [second]	S.B [%]
1	6,02	6,03	6,01	6,02	0,01
10	60,06	60,09	60,04	60,06	0,06
20	120,11	120,14	120,17	120,14	0,09
30	180,19	180,15	180,18	180,17	0,04
40	240,25	240,24	240,29	240,26	0,07
60	360,29	360,31	360,33	360,31	0,04
90	540,41	540,52	540,59	540,51	0,08
120	720,65	720,75	720,82	720,74	0,73
180	1080,89	1080,95	1081,00	1080,95	0,30
240	1441,12	1441,08	1441,20	1441,13	0,37

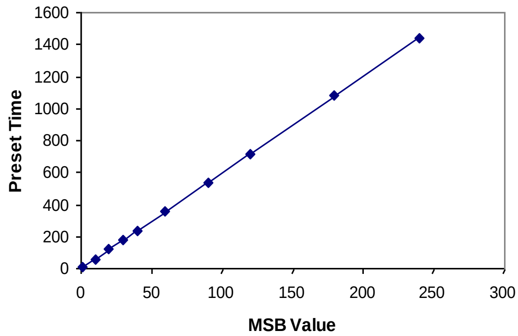

Figure 8. curve of time interval vs content of MSB

● Testing of the main counter

Counter 2 was used as the main counter. The input of the counter was connected to the frequency generator and the frequency was adjusted to ± 4 Hz. Counting was done in four different times (1, 3, 5 and 7 minutes), each counting times were repeated 5 times. The calculation of the average and the deviation standard (SB) was done using formula 1[14] below.

$$(SB)^2 = \frac{n\sum_{i=1}^{n} Xi^2 - (\sum_{i=1}^{n} Xi)^2}{n(n-1)} \quad \text{......(1)}$$

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Where: Xi = counting number and n = repeating number.

The result can be seen in Table 4 where the errors are less than 0.2%.

Table 4. Result of main counter testing

Counting time [minutes]	counting					Average	SB [%]
	1st	2nd	3th	4th	5th		
1	236	236	236	236	236	236	0
3	710	708	709	708	709	708,8	0,1
5	1182	1184	1185	1184	1186	1184,2	0,19
7	1656	1657	1659	1658	1660	1658	0,15

● **Testing using neutron**

Testing was done using sample A-7075 (Al Mg Zn2 alloy) at neutron wavelength of 0.9975 Å. [13]**.** The result can be seen in Figure 9.

Using this control system, repeatability of θ and 2θ angle movement was found better compare to that using the microcontroller since where there was an error about ± 0,5° on the movement of 2θ angle.

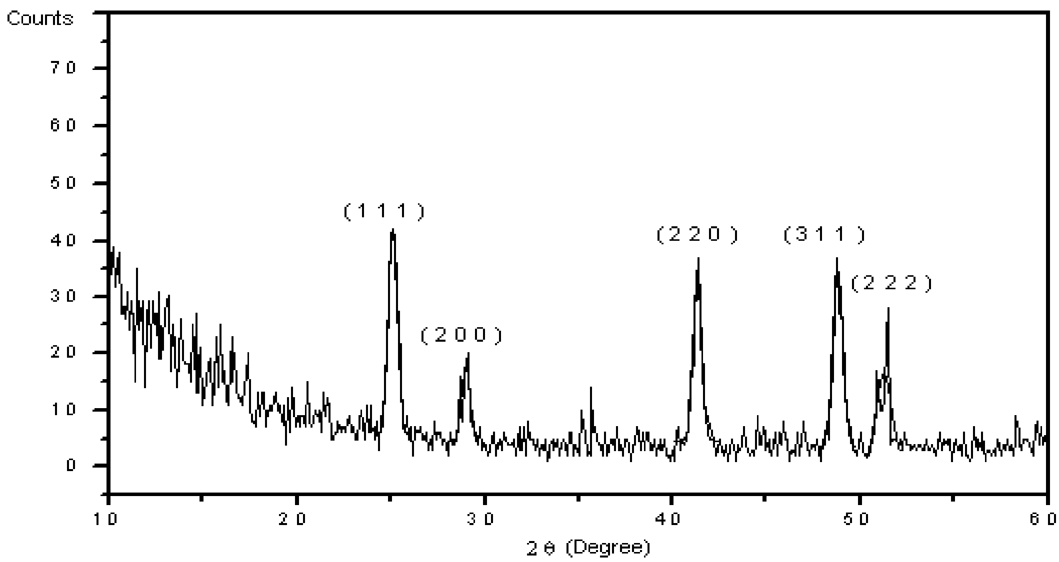

Figure 9. Diffraction pattern of A-7075 (Al Mg Zn_2) alloy diffraction.

●Test result of HRPD Controller

Main counter testing

Testing of 32 main counters was carried out using frequency generator (3.7 Hz) as the input.

All counters were counted 10 times with various preset time: 1, 3, 6, 10 and 15 minutes. Errors (SB) were calculated by formula 1 and the testing result can be seen in Table 5 where the errors are less than 0.5%.

Table 5. Testing result of 32 main counters of HRPD

No. Det.	Preset times [minutes]									
	1		3		6		10		15	
	Average counting	SB [%]	Average counting	SB [%]	Average counting	SB [%]	Average counting	SB [%]	Average counting	SB [%]
1	222	0,00	665	0,17	1329	0,13	2217	0,15	3319	0,12
2	222	0,00	666	0,19	1327	0,13	2217	0,10	3321	0,09
3	222	0,00	666	0,14	1328	0,12	2217	0,14	3318	0,17
4	222	0,00	666	0,12	1327	0,17	2219	0,11	3322	0,09
5	222	0,00	666	0,10	1327	0,21	2219	0,09	3325	0,12
6	222	0,00	666	0,17	1327	0,19	2220	0,14	3325	0,13
7	222	0,00	666	0,10	1327	0,19	2219	0,11	3319	0,09
8	222	0,00	665	0,12	1326	0,24	2218	0,12	3321	0,12
9	222	0,00	666	0,10	1329	0,13	2217	0,15	3218	0,12
10	222	0,00	666	0,32	1327	0,13	2217	0,10	3325	0,17
11	222	0,00	666	0,30	1328	0,12	2217	0,14	3323	0,15
12	222	0,00	666	0,18	1327	0,17	2219	0,11	3320	0,08
13	222	0,00	665	0,31	1327	0,21	2219	0,09	3325	0,12
14	222	0,00	666	0,14	1327	0,19	2220	0,14	3321	0,10
15	222	0,00	666	0,29	1327	0,19	2219	0,11	3323	0,11
16	222	0,00	666	0,14	1326	0,24	2218	0,12	3324	0,11
17	222	0,00	666	0,16	1328	0,12	2219	0,09	3322	0,13
18	222	0,00	666	0,15	1327	0,17	2220	0,14	3328	0,13
19	222	0,00	666	0,22	1327	0,21	2219	0,11	3329	0,10
20	222	0,00	666	0,33	1327	0,19	2218	0,12	3329	0,09
21	222	0,00	666	0,31	1328	0,18	2219	0,09	3325	0,11
22	222	0,00	666	0,18	1326	0,24	2220	0,14	3322	0,10
23	222	0,00	666	0,32	1330	0,24	2219	0,11	3329	0,08
24	223	0,33	670	0,57	1332	0,30	2235	0,28	3355	0,26
25	224	0,42	668	0,26	1329	0,13	2222	0,11	3330	0,07
26	223	0,42	666	0,15	1327	0,13	2217	0,10	3330	0,10
27	222	0,00	666	0,16	1328	0,12	2217	0,14	3328	0,08
28	222	0,00	666	0,32	1327	0,17	2219	0,11	3325	0,11
29	222	0,00	666	0,14	1327	0,21	2219	0,09	3326	0,12
30	222	0,00	666	0,29	1327	0,19	2220	0,14	3326	0,11
31	222	0,00	666	0,15	1327	0,19	2219	0,11	3322	0,09
32	222	0,00	665.7	0,16	1326	0,24	2218	0,12	3319	0,08

Testing of HRPD using neutron

Finally testing was carried out using the neutron beam on alumina and silicon samples. The result can be seen in Figure 10.

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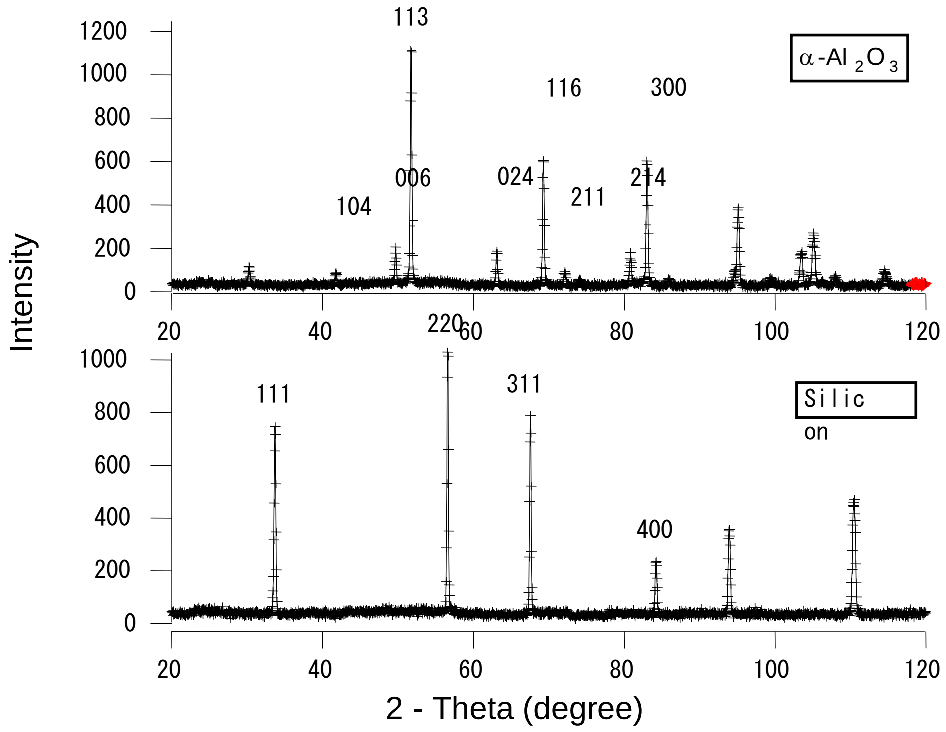

Figure 10. Plots of intensities versus 2 theta angle of alumina and silicon samples

Testing of TAS controller

After finishing with the construction of TAS control system, then the testing performance of TAS controller was carried out.

The test result can be seen in Table 6 and finally tested using the neutron beam with Ni standard samples. The result can be seen in Figure 11.

Table 6. Testing result of TAS movement

Motor name	Direction 0 (nol)	Direction 1 (one)	Limit Switch	Step /Scale	Zero position
RYs	C.C.W	C.W	O.K	840/°	O.K
RXs	C.C.W	C.W	O.K	710/°	O.K
Xs	C.C.W	C.W	O.K	500/mm	O.K
Ys	C.C.W	C.W	O.K	500/mm	O.K
θs	INCREASE	DECREASE	O.K	500/°	-
2θs	INCREASE	DECREASE	O.K	500/°	-
RYa	C.C.W	C.W	O.K	500/°	O.K
RXa	C.C.W	C.W	O.K	1000/°	O.K
ωa	BACKWARD	FORWARD	O.K	500/°	O.K
θa	BACKWARD	FORWARD	O.K	500/°	-
2θa	NEGATIF	POSITIF	O.K	500/°	-
ω1	BACKWARD	FORWARD	O.K	500/°	O.K
ω2	BACKWARD	FORWARD	O.K	500/°	O.K
Cm	BACKWARD	FORWARD	O.K	2000/°	-
Xm	C.W	C.C.W	O.K	1000/°	O.K
Ym	C.C.W	C.W	O.K	1000/°	O.K
RXm	C.C.W	C.W	O.K	500/°	O.K
θm	C.C.W	C.W	O.K	800/°	-

In the testing there was no error found on the movement of the TAS because all parts use a fine mechanic system, even on the forward and backward movements there was no backlash.

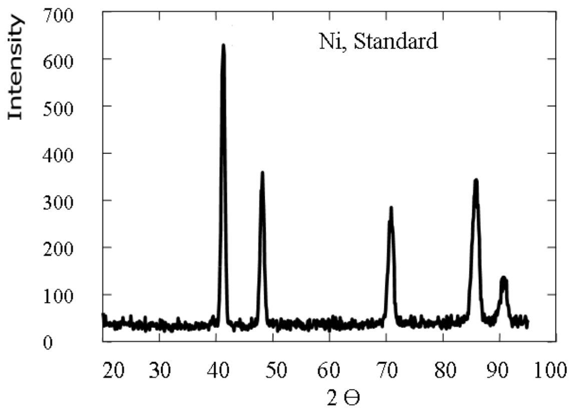

Figure 11. Plots of intensities versus 2 theta angle of Nikel samples

CONCLUSIONS

Testing of the FCD/TD control system was done with and without neutron, the results of both with and without neutron are good. This controller has been used since 2001 and it is found that this new system is more stable than the previous controller. HRPD control system has been used since 2003, the accuracy of 2θ angle is 0.01° which is better than the original controller made by Rigaku – Japan, it was 0.05°. TAS control system has been used since 2004. The configuration of this controller is very simple compared to the original controller made by Rigaku - Japan. It will be perfect if the encoder controller can be activated to remove the parallax error when reading the angle position.

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