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The IPNS Chopper Control and Accelerator Interface Systems*

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Introduction

Several of the instruments at the Intense Pulsed Neutron Source (IPNS) at Argonne use rotating Fermi choppers. The techniques used to control the speed and phase of these rotating devices will be discussed in the following paragraphs.

Chopper Mechanical Overview

The neutron chopper rotor is of cylindrical Fermi design and constructed of hemicylindric beryllium lunes with a curved slot containing a slit package which permits neutrons to pass through[1]. The chopper rotation axis is vertical with high precision ball bearings being used both top and bottom. To remove heat generated by the motor and bearings, the chopper is operated in a 1 mm Hg He atmosphere. This provides adequate cooling, yet presents insignificant drag. The driving motor is of hysteresis-synchronous type and has a rated power of 90 W. The hysteresis-synchronous motor is attractive in demanding little sophistication of the drive system, and its torque is good during startup; however, its synchronous torque is low, and acceleration must also be done slowly to avoid hysteresis heating of the rotor which can damage the bearings. Fig. 1 shows a sectional view through the slit package assembly and provides parameters for the 5 chopper rotors currently in use at IPNS. The calculated geometric transmission efficiencies can be seen in Fig. 2 and the calculated neutron burst widths can be observed in Fig. 3. The IPNS chopper rotors are operated at a multiple of 30 Hz frequency (typically 270 Hz) and synchronously with the IPNS Rapid Cycling Synchrotron (RCS) which operates at a nominal frequency of 30 Hz [2]. The chopper drive and protection system provides the power required to operate the chopper at a chosen speed, monitors operating parameters and shuts down the chopper power if a potentially damaging condition exists. Amplifiers operated as constant current sources are used to supply the driving power to the chopper.

Chopper Drive and Phasing Systems

Monochromatization of the incident neutron beam is accomplished by opening the chopper at a well defined time after the proton beam hits the IPNS target. By this means, only neutrons whose velocities bring them to the chopper at the chosen time can pass through it and strike the sample. In order that energy resolution not be degraded, the chopper - proton beam phase (i.e., the above mentioned time delay between protons on target and the opening of the chopper) must be held constant to a tolerance of no more than 10 - 20% of the source burst time, or typically to a few microseconds. In order to accomplish this, systems to control both the chopper and certain functions of the RCS have been developed. These are divided operationally into a drive system, which provides the power required to run the chopper at a chosen speed, monitor chopper operating parameters and shuts

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off chopper power (scram) if a potentially damaging condition exists; and a phasing system, which maintains the desired phase relationship by adjusting the chopper phase when necessary and by issuing extraction trigger signals to the RCS.

Chopper Drive System

The drive system provides power to run the chopper at a chosen frequency and scrams the chopper if a potentially damaging condition is sensed. The various components of this system can be seen in the block diagram displayed in Fig. 4.

System Master Clock -

The Master Clock provides signals to which the RCS and choppers can be synchronized. A 60 Hz square wave is sent to the RCS where it is converted to a 30 Hz sine wave to drive the ring magnet power supply. To the 30 Hz delay (see below) of each chopper phasing system are sent a 30 Hz square wave and a 3.93216 MHz clock. The high frequency is used in synthesizing audio frequencies to run the choppers; the 30 Hz signal provides a timing reference for phase locking of the chopper drive frequencies and for phase shifting during extraction control. There are actually two versions of the Master Clock, one which operates from a fixed crystal-controlled 3.93216 MHz oscillator and a Variable Frequency Master Clock (VFMC) unit[3] which allows the oscillator frequency to change slightly in response to slow changes in the power line frequency. The latter is used to minimize operating difficulties experienced by the RCS when the 60 Hz clock frequency differs significantly from the power line frequency. Also, development work is currently underway which will allow the chopper systems to operate synchronously with the (VFMC). This activity will be discussed further in the **Summary and Future Plans** section (see below).

In addition, a 60 Hz Backup Clock is located in the RCS control room. In the event of interruption of the master 60 Hz signal coming into the accelerator main control room, the Backup Clock synchronously switches the RCS over to its own 60 Hz reference signal. This is done to protect the Ring Magnet Power Supply System from possible damage due to sudden removal of its input signal, and to prevent the RCS shutting down when something goes wrong with the Master Clock or associated cabling.

Frequency Synthesizer -

This unit synthesizes two-phase sine waves with frequency between 1 Hz and 960 Hz. It is designed so that at any harmonic of 30 Hz its outputs can be phase-locked to an external 30 Hz reference. This allows both the Frequency Synthesizer and the RCS to be synchronized to the System Master Clock for chopper-RCS phasing. The Synthesizer can operate in a stand-alone mode using its internal frequency standard. For use with the phasing system, the required 30 Hz and 3.93216 MHz signals are brought from the Master Clock (see above) via the 30 Hz Delay Module.

An automatic frequency increase feature has been provided to simplify chopper acceleration. This feature is controlled by the FAST-STOP-SLOW switch on the front panel. With the switch in either the FAST or SLOW position, the synthesizer frequency will be changed from the current value to a specified harmonic of 30 Hz; the harmonic number is dialed in using thumbwheels. The frequency is increased (or decreased) in steps of 1/8 Hz; the rate at which step changes are made is controlled by a front-panel adjustment in the SLOW mode, or at a fixed rapid rate in the FAST mode. Adjustment of the SLOW rate is set to provide continuous chopper acceleration over a wide frequency range while maintaining a slip frequency of less than 1/8 Hz. This minimizes the hysteresis heating of the chopper and the potential damage to bearings during the acceleration process. The FAST mode is used to reset or preset the synthesizer to a desired frequency. The frequency ramping process can be frozen at any point by switching to STOP mode.

Damper -

Small variations in bearing frictional drag cause an increase in the chopper phase instability (hunting). This condition results in small changes in the chopper speed. A fast acting logic circuit within the Damper Module[3] senses the variations in chopper speed and makes small phase shift corrections in the driving sinusodial waveforms to the chopper which minimizes the hunting effects, extends the useful bearing lifetime and improves data collection efficiencies.

Chopper Drive Regulator -

This unit controls two power amplifiers (see below) which actually drive the chopper. It is a constant-current regulator which maintains the rms current in both phases at a specified value. A sufficiently long time constant is built into the regulating circuit such that current fluctuations due to hunting oscillations of the chopper are ignored. The Regulator requires as input the two fixed amplitude sine wave outputs of the Frequency Synthesizer or the Frequency Synthesizer - Damper series combination, and a current sense signal from each power amplifier (see below). As output it produces two variable level sine waves, one to drive each amplifier. The two phases are regulated, independently of each other, to the same rms current value by controlling the amplifier inputs. Current monitor outputs are also provided for the chopper Scram Module (see below). The rms current of each phase is displayed on a front-panel meter reading 0-5 amps, and is adjusted using a front panel control.

Chopper Scram -

The Chopper Scram unit contains a microprocessor which cyclically monitors the current levels in the two phases, the vibration amplitude and the chopper-oscillator slip frequency. If any of these are outside the set trip levels, a scram signal is sent to shutdown the power amplifiers and secure the data acquistion system. A RUN-STANDBY switch is provided to defeat the scram function during chopper acceleration.

Power Amplifiers (California Instruments Co. Model 501TC) -

The Power Amplifiers, one for each phase, are 500 VA rated units with output voltage capability from 0-135 or 0-270 volts. Since we require large currents only during magnetization (4 to 5 amps.), the 0-135 volt taps are used. A solid state relay switches the AC power to the Power Amplifier. This relay is opened by the Chopper Scram Module to shut off the Power Amplifier when a scram condition exists (see above). A 0.1 ohm current sense resistor has been added in series with the output. The voltage across this resistor is monitored by the Chopper Drive Regulator (see above).

Zero Crossing Detector and Vibration Monitor -

This module converts the bipolar pulse from the chopper magnetic pickup to a logic pulse for use by the Chopper Scram and Chopper Phase Controller. In addition, it provides power to the accelerometer used to monitor chopper vibration and converts the vibration signal amplitude to a DC level for the Scram Module.

Chopper Phasing System

The control functions performed by the phasing system may be most readily understood with reference to the timing diagram of Fig. 5. For illustration we ignore the possibility of using a second chopper.

In order for the chopper to stay in phase with the accelerator, the chopper frequency (1/CHOP) must be a multiple of the 30 Hz RCS frequency (270 Hz is a typical value). The fundamental condition which must be met is that the chopper opening time follow the proton on target signal (T-o) by the specified time (Tc), with a tolerance (ΔTc) as shown. The phasing system controls proton beam extraction (EXM) and therefore (T-o), so all it needs do to establish the desired phase is to send an extraction trigger signal (EXM) such that (CpEx = CHOP - Dly - Tc).

There are limits, of course, on the times during the RCS cycle when the beam may be extracted. A window is provided by the RCS clock during which extraction trigger pulses are accepted; if an extraction trigger pulse arrives within this window, then the chopper will control the extraction of the proton beam. This condition is operational only when the chopper can control (CCC) level being sent to the Chopper Controller is high. A low (CCC) level indicates that extraction is being controlled by the RCS and that extraction will take place at the center of the extraction window, which is the optimum instant from the machine's point of view. As long as the (CCC) level is high, the RCS clock will wait for a chopper extraction trigger pulse (EXM) until the last possible moment; if none arrives, the beam will be extracted at the trailing edge of the extraction window. Even with a high (CCC) level, it is not certain that every (EXM) will control extraction of the proton beam. The phasing system therefore checks every (T-o) pulse to make sure the phase condition is satisfied, i.e., that (T-o) arrives within the time interval equal to (CpEx + Dly ± $\Delta Tc/2$). If this condition is not satisfied, an inhibiting level is sent to the data acquisition system (DAS) front-end computer so data will be accumulated only for correctly phased pulses.

The final function of the phasing system is to adjust the phase of the chopper with respect to the RCS when necessary in order that legal extraction trigger pulses (i.e., within the extraction window) can be sent. This is accomplished by introducing a delay between the "Master" 30Hz signal used to drive the RCS ring magnets and the audio frequency (twice chopper frequency, typically 540 Hz) used to drive the chopper. Exactly when this phase shifting occurs will be described below in the discussion of the Chopper Controller Module.

Chopper Mode Selector -

The Chopper Mode Selector Module simulates several modes of accelerator operation. One of these modes is the normal running state of the RCS in which all system components are phase-locked to the 30 Hz Master Clock and all required signal information is communicated between the Chopper Mode Selector and the Chopper Controller Module. This mode is most frequently used to prephase choppers prior to accelerator start-up and also to test the performance of chopper phasing equipment without wasting neutron beam time. Other available modes are used for the testing and evaluating of new chopper control and phasing circuitry, such as the variable frequency mode of operation which will be discussed later.

Priority Level Selector -

This module is the only one which actually communicates with the RCS. It receives the extraction window (EW), protons on target (T-o), chopper can control (CCC) signals and sends out the extraction signal (EXM).

The Priority Level Selector also communicates with up to six Chopper Controllers (see below) and prioritizes the information it receives from them. Each controller receives extraction window and protons on target information from the Priority Level Selector and sends back its own extraction trigger. The Priority Level Selector sends to the RCS the highest priority legal extraction trigger (EX) it receives for each RCS cycle. Thus if the first priority (EX) signal is not within the extraction window, the second priority (EX) will be used, etc. If there is no (EX) signal from any of the six inputs which is within the extraction window, the RCS will extract the beam at the trailing edge of the extraction window. At any instant, the highest priority chopper providing a legal (EX) pulse is defined to be the "Master", all others "Slaves". This status information is sent back to each Chopper Controller and is used during phase shifting (see below).

Chopper Controller -

Each chopper which is to be phased has one of these modules. The module contains a microprocessor and some timers which are used by the processor to gather the information it needs. The processor and timers are clocked using a 2 MHz oscillator. Upon initialization, the processor does the following:

a) Measure the chopper period (CHOP) (see Fig. 5).
b) Measure the extraction window (EW) width (typically 200 μs).

c) Measure the delay (Dly) from extraction (EXM) to (T-o) (typically 54 µs).

d) Read the desired value of Tc from the thumbwheel switches and compute the delay time (CpEx) by which the extraction trigger (EXM) must follow the chopper pulse.

e) If the resulting extraction pulse (EXM) does not fall within the limits of the extraction window, phase shift the chopper to bring (EXM) to the midpoint of the extraction window.

At this point the (EXM) is being sent at the optimum time (midpoint of the extraction window) and no futher corrective action is needed until the chopper - RCS phase changes. If such a phase change occurs, corrective action will only be taken if (EXM) has moved a distance equal to 25% of the extraction window width either side of the center of the extraction window. When this condition exists, the Chopper Controller will phase shift the chopper to return the (EXM) to the midpoint of the extraction window.

In addition, every incoming (T-o) pulse is checked to make sure it satisfies the chosen phasing conditions. If the phasing conditions are not met, a blanking signal is sent to the (DAS) to disable data collection for that burst of neutrons. A delayed (T-o) pulse (100 µs) is used to start the (DAS); this allows the Chopper Controller time to determine if the chopper is phased correctly and if not, to generate a data blanking signal.

30 Hz Delay -

This module provides the means by which the Chopper Controller can phase shift the chopper. A variable delay is introduced into the 30Hz sync signal from the Master Clock and the delayed 30Hz is used by the Frequency Sunthesizer to phase-lock the chopper driving waveforms. Thus the chopper can be phase shifted with respect to the Master Clock, while the RCS is locked to the undelayed master 30Hz signal.

Summary and Future Plans

The present IPNS Chopper Control and Phasing System was designed and constructed at Argonne during 1981-1982 and required about one year of on-line experience to recognize and eliminate system problems. Since that time, the original system has performed well with no loss of neutron beam time due to electronic failures in any of the Chopper Control or Phasing System hardware. As would be expected, areas for improvement have surfaced over the past 2 1/2 years of routine chopper operation; namely, the desirability to operate the RCS - chopper system in a 60Hz power line phase-locked configuration. This mode of operation is most efficient for the RCS as beam losses during the proton acceleration cycle are minimized and therfore, radiation activation rates for accelerator components are also reduced and neutron fluxes are maximized. Because of the low horsepower motors used to supply power to the choppers, it is not possible to maintain synchronous chopper operation while phase-locked to the 60Hz power line.

A Variable Frequency Master Clock (VFMC) unit[3] has been designed which allows the oscillator frquency to change slightly in response to slow changes in the power line frequency. Measurements made while operating phase-locked to the (VFMC) show that RCS porformance is not degradated by small phase shifts (±15°) relative to the 60 Hz power line; also, the chopper system data collection efficiency remains at the 98-99% level.

Recall that during initialization (see Fig.5), the chopper period (CHOP) and the extraction delay time (Dly) are measured and stored as constants. For each pass through the microprocessor software, the (Tc) value is read and the value of (CpEx) is computed from the relation (CpEx = CHOP - Dly - Tc) and used to generate the next extraction trigger pulse (EXM). The value of (Tc) is determined from a chopper calibration table and set into the front panel thumbwheel switches of the Chopper Controller. This allows an experimenter to change the neutron energy selected by the chopper at any time without impacting the stability of the chopper control-phasing system. Operation using the Variable Frequency Master Clock (VFMC) requires continuous measurement of the chopper period (CHOP). As can be seen from Fig. 5, any variation in the chopper speed will change the time when the chopper window is open (Tn); therfore, (ΔCpEx) reflects the changes in (Tn) due to the variations in the chopper period (CHOP) and corrects for the smearing of the neutron energy which would result if a correction were not made for (Δ Tn).

A new Chopper Controller has been designed and built [4] at Argonne to function in both the fixed and variable frequency modes of operation. An 8 bit microprocessor and newly developed 100 MHz counting circuitry have been brought together to produce a controller having a 10 nanosecond clocking uncertainty. The spectral data displayed in Fig. 6 was produced by routing appropriately reshaped chopper Zero Crossing Discriminator (ZCD) pulses into a detector input of the (DAS). The resultant spectral widths indicate the total timing uncertainty of the Chopper Controllers plus 125 nanoseconds timing uncertainty of the data acquisition system (DAS).

Neutron measurements, obtainted while operating synchronously with the Variable Frequency Master Clock, indicate that the new Chopper Controllers are functioning as intended. Fig. 7 shows the agreement between Monitor 1 (located downstream of the chopper) spectra collected on the High Resolution Medium Energy Chopper Spectrometer (HRMECS) for both fixed and variable frequency modes of operation. These data clearly verify that spectrometer energy resolution is not deminished through the use of synchronous variable frequency chopper phasing techniques. It is expected that the Variable Frequency Master Clock will remain as the standard time base for the routine operation of the IPNS RCS-Chopper Phasing System.

Short bearing life (typically 25 to 50 days) continues to be the weak link in the reliability of the IPNS choppers. Given sufficient funds, we feel it would be advantageous to investigate the possible use of commercially available magnetic bearing systems.

References

[1] R. Kleb, C. A. Pelizzari and J. M. Carpenter, "Fermi Choppers for Epithermal Neutron Beams," (Argonne), in preparation

[2] A. Rauchas, G. Ostrowski, C. Pelizzari and G. Volk, "IPNS Accelerator System and Neutron Chopper Synchronization," (Argonne) Proc. ICANS-VII (1983), p157

[3] L. Donley, "Phase Locking the IPNS Neutron Chopper to the 60 Hz Power Line," (Argonne) Proc. ICANS-VIII (1985)

[4] E. Jung, "Precision Phase Control of High Speed Rotating Devices Using An 8 Bit Microprocessor and 100 MHz Timing Circuitry," (Argonne), in preparation

CHOPPER PARAMETERS

Rotor	50-2	160-2	500-2	250-3HR	500-3HR
f (rpm)	16200 ->				
f (hz)	270 ->				
E (meV)	50	165.3	500	250	500
R (in.)	35.886	65.253	113.480	80.244	113.480
D (in.)	6.063 - - - - - - - - - - - - ->			5.000 - - - - - ->	
d (in.)	.100	.080	.062	.050	.040
τ(μs. fwhm)	9.72	7.77	6.03	5.89	4.72
Beam size (in.)	2w x 4h	2w x 4h	2w x 4h	3w x 4h	3w x 4h
Geomet. Trans.	0.82	0.79	0.74	0.78	0.74
Adsorber	3 ply B-Al - - - - - - - - - ->			2 ply B-Al - - ->	

Adsorber constructed by cross laminating 5.7 mil dia. Boron fibers produced by vapor depositing Boron on 0.5 mil dia. Tungsten wire.

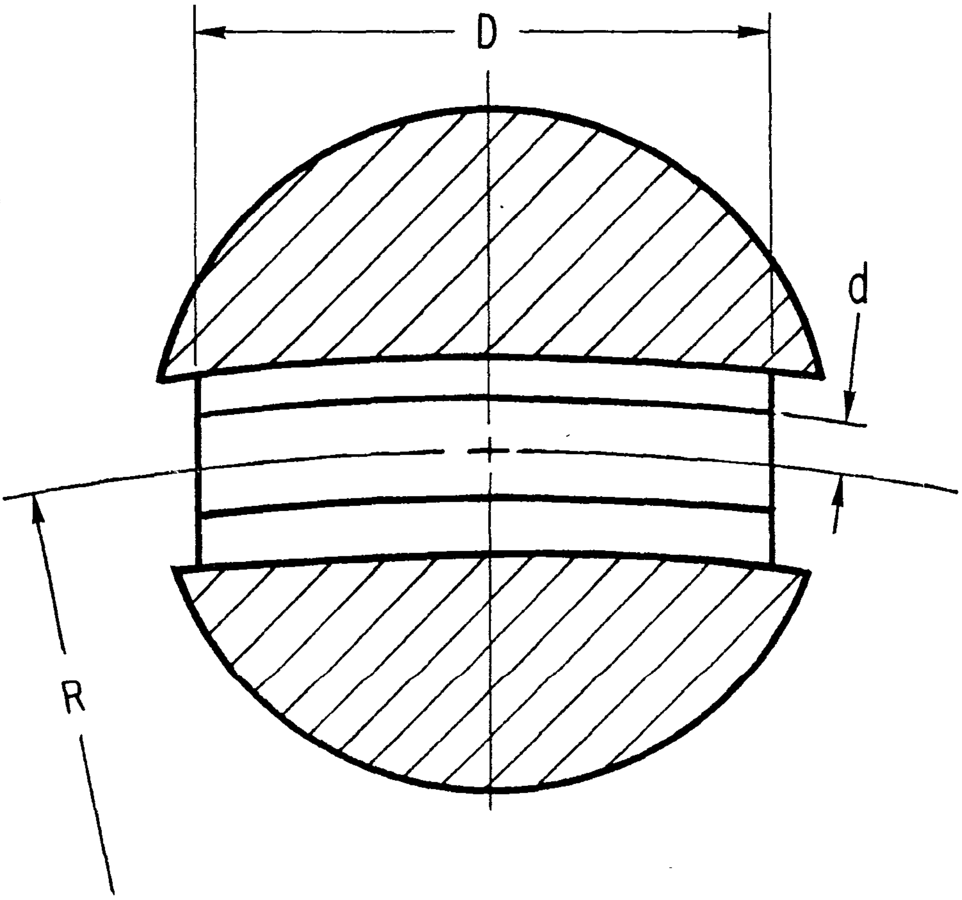

Fig. 1 - Parameters for the 5 IPNS Chopper Rotors

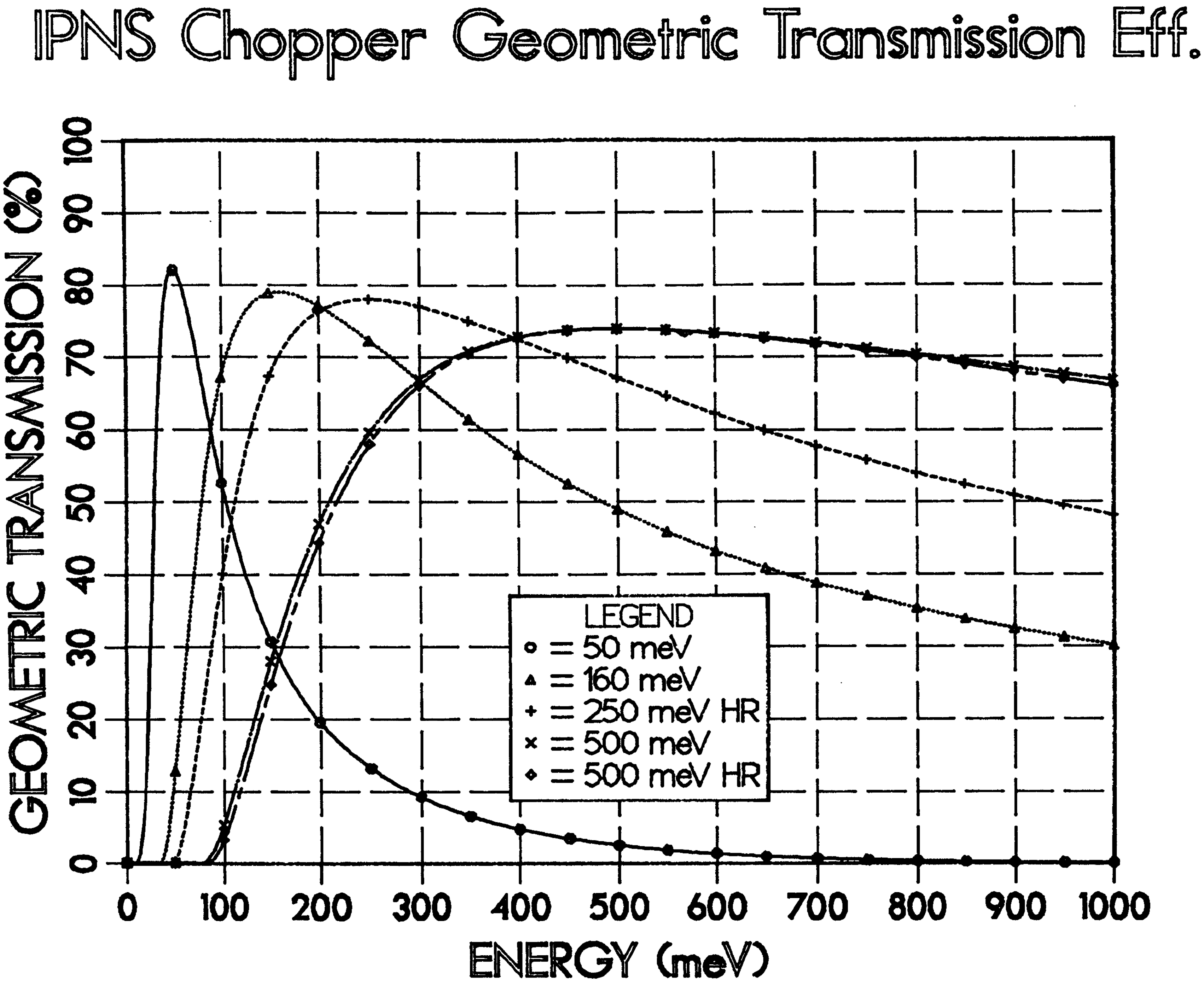

Fig. 2 - Computed Geometric Transmission Efficiencies for the IPNS Chopper Rotors

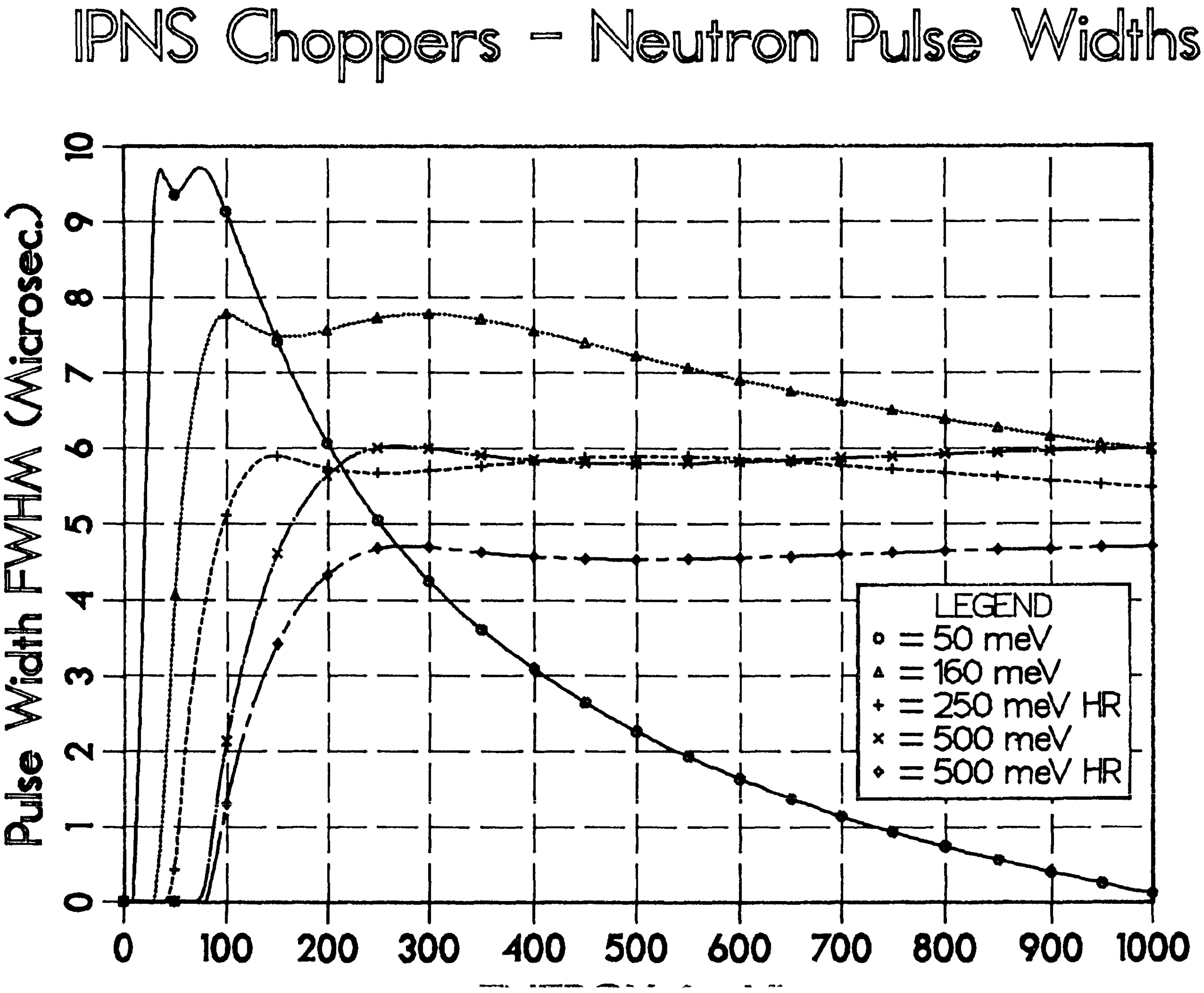

Fig. 3 - Computed Neutron Burst Widths (fwhm) for the IPNS Chopper Rotors

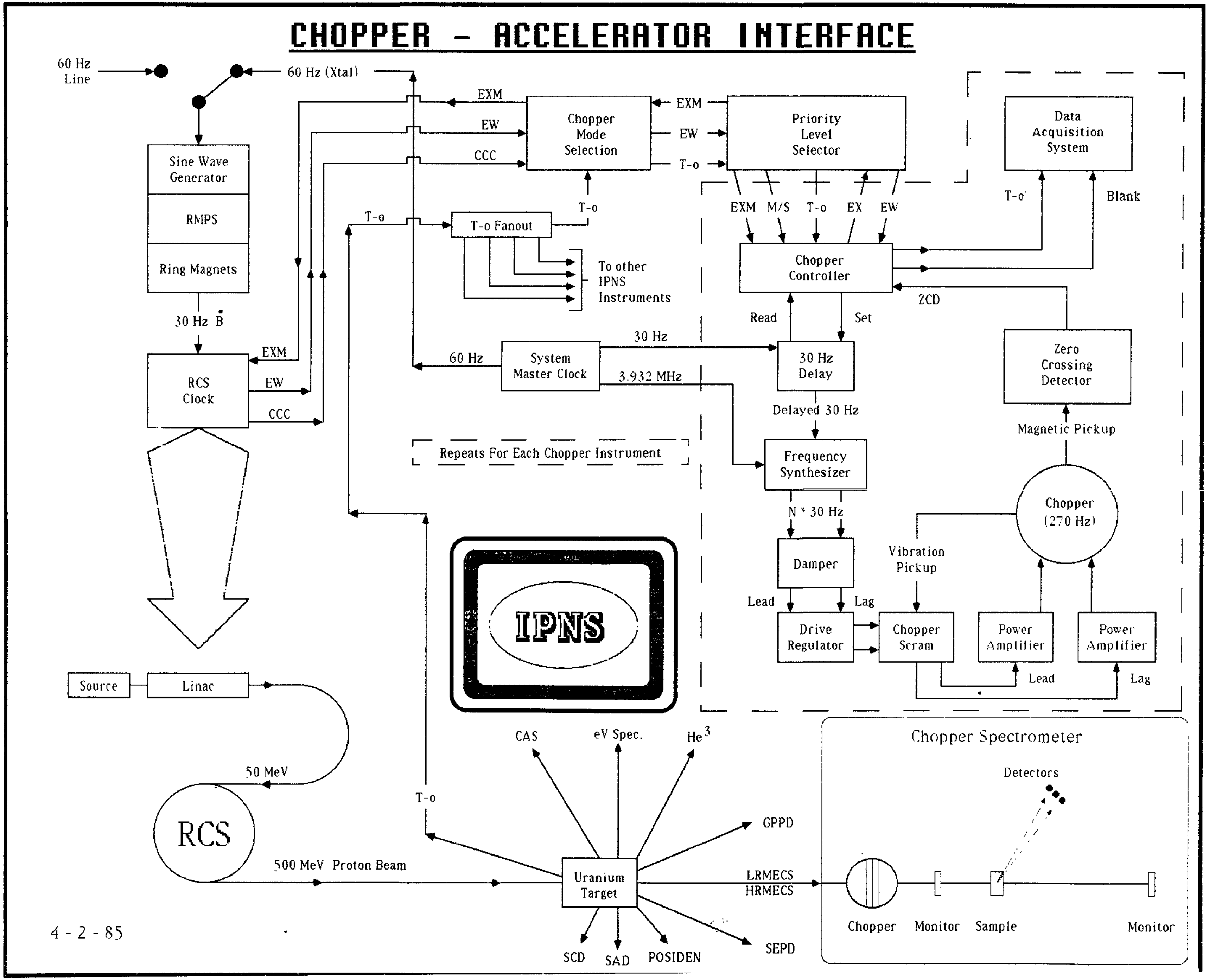

Fig. 4 - Block Diagram of the IPNS Chopper Control and Phasing System

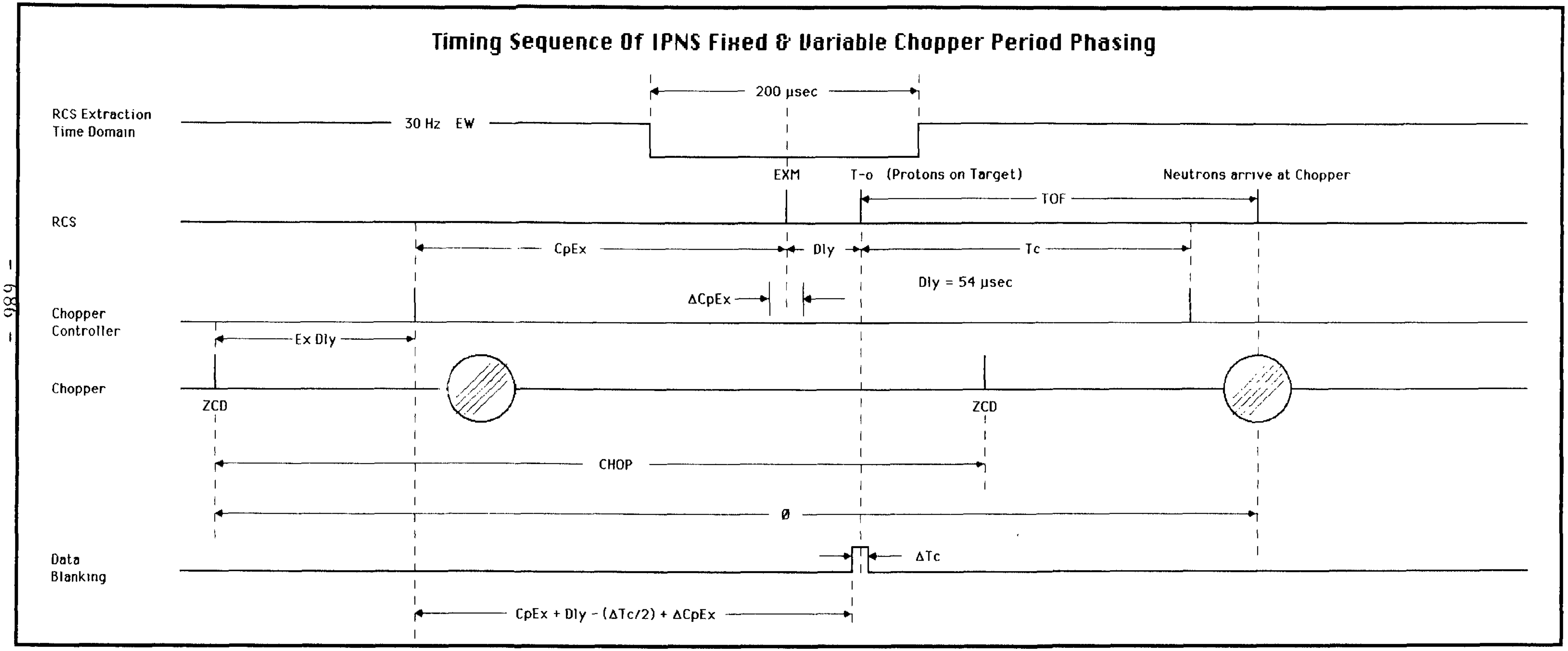

Fig. 5 - Chopper Phasing Timing Diagram

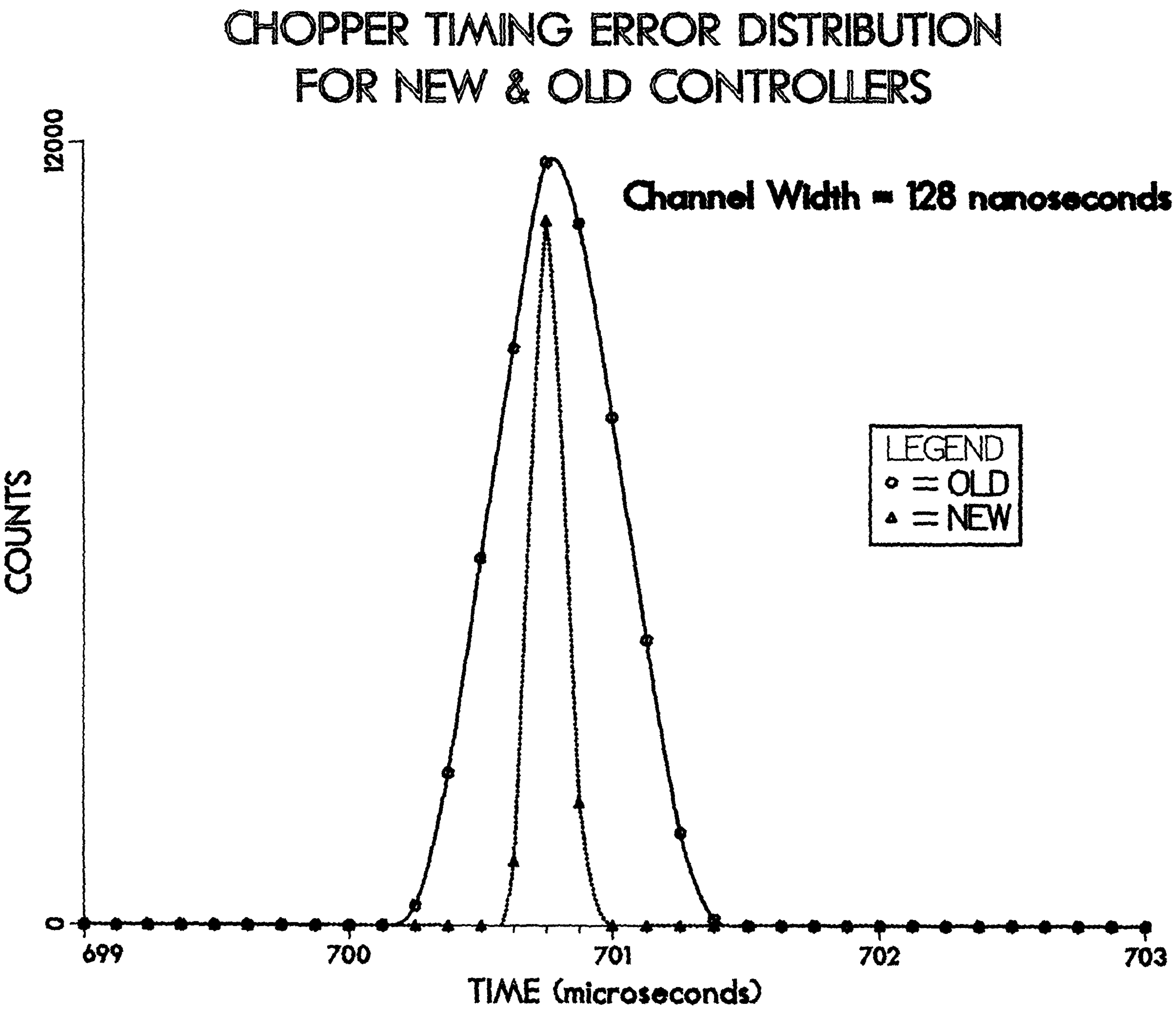

Fig. 6 - Time-of-flight Spectra of Neutron Chopper Pulses Showing Timing Uncertainties in Old and New Chopper Controllers

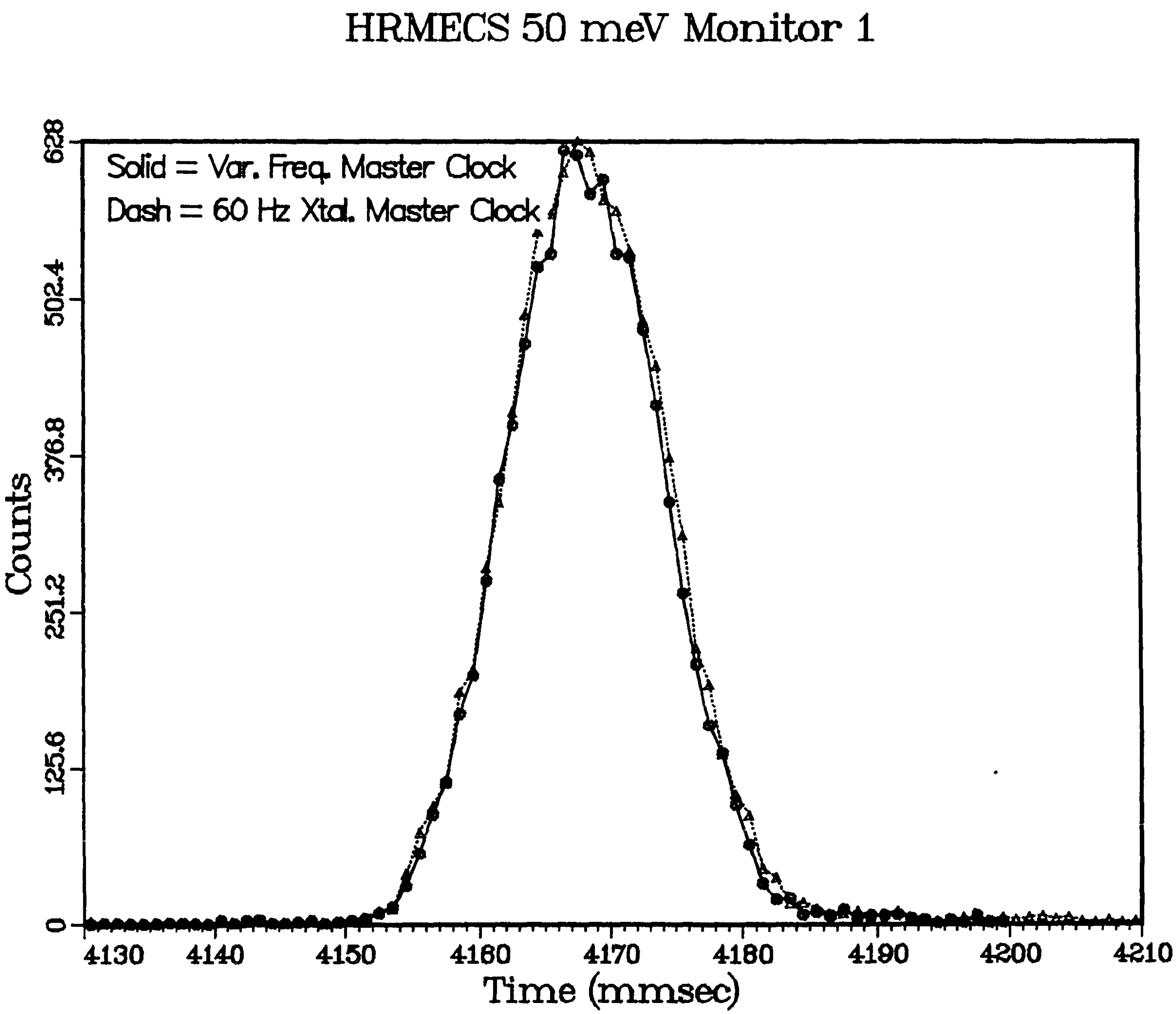

Fig. 7 - Time-of-flight Monitor Spectra for Fixed and Variable Frequency Chopper Operation