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Optimization Study of Coupled Hydrogen Moderator with Extended Premoderator

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Abstract

We performed an optimization study of an extended premoderator (PM) for a coupled supercritical hydrogen (H_2) moderator in a lead reflected system. We found that the extended PM could eliminate a backside PM which had been believed to be indispensable from a neutronic point of view. This means that neutron beams can be extracted from both viewed surfaces of one moderator, so that two H_2 moderators can be replaced by one H_2 without sacrificing neutron intensity.

In this paper, we compared neutronic performances of these two moderator systems; one-moderator system and two-moderator system. Neutron beams are extracted from both viewed surfaces in the former, while in the latter two H_2 moderators having one viewed surface, respectively, share the PM in the backside. We concluded the one-moderator system exhibits a better neutronic performance with a lower heat deposition in H_2comparing to the two moderator system.

We briefly compared the neutronic characteristics between the lead and beryllium reflected system. It was found that the lead reflected system can provide a higher pulse peak with a narrower pulse width and a faster decay time than the beryllium one, although the time-integrated intensity is lower than the latter.

1 Introduction

For the Japanese spallation neutron source (JSNS) [1], we originally proposed a set of two coupled supercritical hydrogen (H_2) moderators with premoderator (PM) sharing the backside PM in the backside. The two H_2 moderators were put together at the maximum leakage-neutron luminosity region on the target by sharing the backside PM to enhance the cold neutron intensities from both moderators [2, 3]. It had also been proved that the extension of PM enhanced cold neutron intensities appreciably without sacrificing the pulse shape [4]. This result suggests that the backside PM can be eliminated and the two H_2 moderators can be replaced by one H_2 moderator at no penalty in neutron intensity. The one-moderator system (1-MS) is thought to be superior to the two-moderator system (2-MS) from viewpoints of moderator handling, safety, reliability and cost saving. In addition, the pulse shapes are expected to be improved. This paper describes the optimization of the H_2 moderator thickness and the length of PM extension in a lead (Pb) reflected system with discussions about the performances of the 2-MS and 1-MS.

On the other hand, it is being recognized that an extended PM enhances neutron intensities not only in the Pb reflected system but also in the beryllium (Be) one. We briefly compare the neutronic characteristics of both systems.

2 Calculations

We calculated the characteristics of neutron beam from a coupled H_2 moderator and energy deposition (E_{dep}) in H_2 using NMTC/JAERI-97 [5] and MCNP4A [6]. For a mercury, cross sections evaluated at JAERI [7] were used. The cold neutron intensities were estimated as an integration of the Maxwellian portion (I_{int}). Pulse peak intensities (I_{peak}), pulse width in full width at half maximum (FWHM) and decay times were calculated for 2.1 meV neutrons. The calculation models of the 2-MS and 1-MS are shown in Fig.1. The thickness of the PM was fixed at 25 mm in this study because the I_{int} was maximum at 25 mm in the previous study about the PM thickness without extension [4]. The general parameters used in the calculations are summarized in Table 1. The configuration of target-moderator-reflector system used in this study was the same as used in references. [2, 3] The detail of the model and the calculation method are also given in the literature.

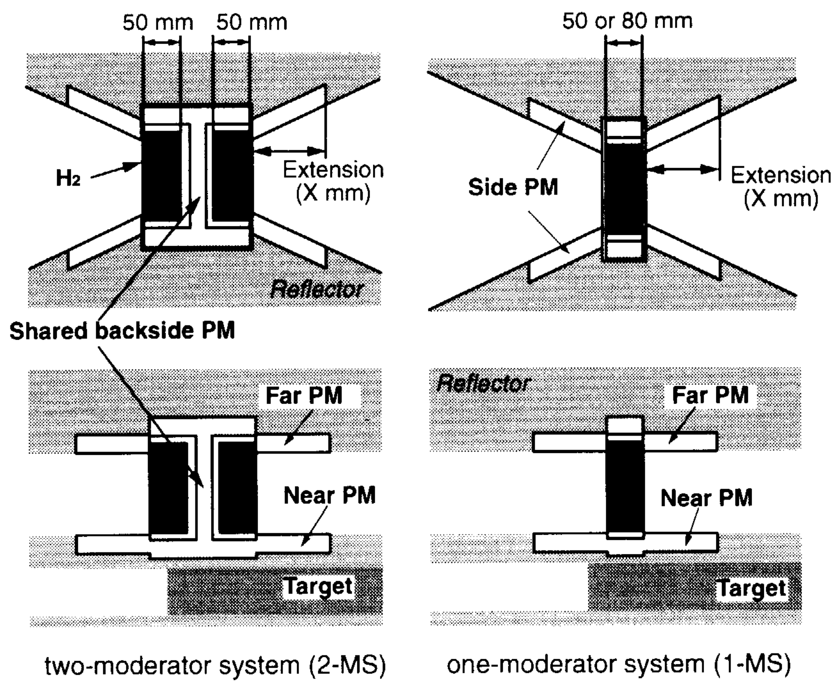

Fig. 1 Calculation models of a coupled moderator for the 1-MS and 2-MS. The upper is horizontal view, the lower is vertical view.

Table 1 General parameters for calculational model

Proton beam	
Power	5 MW
Energy	1.5 GeV
Repetition rate	50 Hz
Current density profile	Rectangular (flat distribution)
Cross section	133.5×51.6 mm^2
Target	
Material	Mercury (Hg)
Dimension	$173.5^W \times 81.6^H \times 600^L$ mm^3
Reflector	
Material	Lead (Pb)
Shape	Modified octagonal horizontal cross section
Main dimension	$800^W \times 1600^H \times 1200^L$ mm^3

3 Optimization study in a lead reflected system

3.1 Effect of backside premoderator

We examined the effect of the shared backside PM on the enhancement of I_{int}. The calculation was performed with and without the backside PM. It was found that the neutron intensities below 100 meV decreased only about 5% by removing the backside PM. This is due to the fact that the extended PM enhances the intensity considerably. This result means that the backside PM is no longer important after introducing the extended PM, namely, the 1-MS with extended PM can provide comparable neutron intensity to the 2-MS which we have proposed at early time.

3.2 Thickness of hydrogen moderator

We estimated the effect of each part (near, side, far) of PM extension in the 1-MS as shown in Fig.1. The extensions were applied for the near, side and far PMs with respect to the target.

The I_{int} increases, more or less, with the extension of each part as shown in Fig.2. Of course, the near PM brought about the maximum enhancement. Therefore, the extension should be applied for all part of PM. The effects of PM extension in the 2-MS are compared with the 1-MS in Fig.2. The achieved I_{int} in the 1-MS was

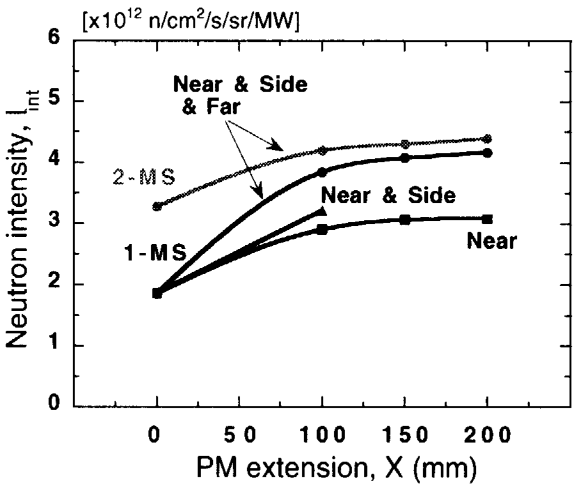

Fig. 2 Effects of each part of PM extension on neutron intensities.

smaller than that in the 2-MS, although the effects of extensions were much larger in the 1-MS than the 2-MS.

The reason why the 1-MS could not surpass the 2-MS in I_{int} may be due to the thinner effective thickness of H_2. The thickness of a H_2 moderator can be increased for the 1-MS if the pulse characteristics are acceptable. Figure 3 shows the effects of H_2 thickness on I_{int} and FWHM from the 1-MS without PM extension. The size of the PM surrounding the H_2 was changed with the H_2 thickness. For comparison, the I_{int} from the 2-MS (moderator thicknesses are 50 mm) with and without PM extension are also shown. The I_{int} from the 1-MS rapidly increases up to 80 mm thickness and gradually at about 120 mm. However, it could not surpass the 2-MS. The FWHM continuously increased with the H_2 thickness. Therefore, we selected 50 mm and 80 mm H_2 moderator for the optimization study of the PM extension.

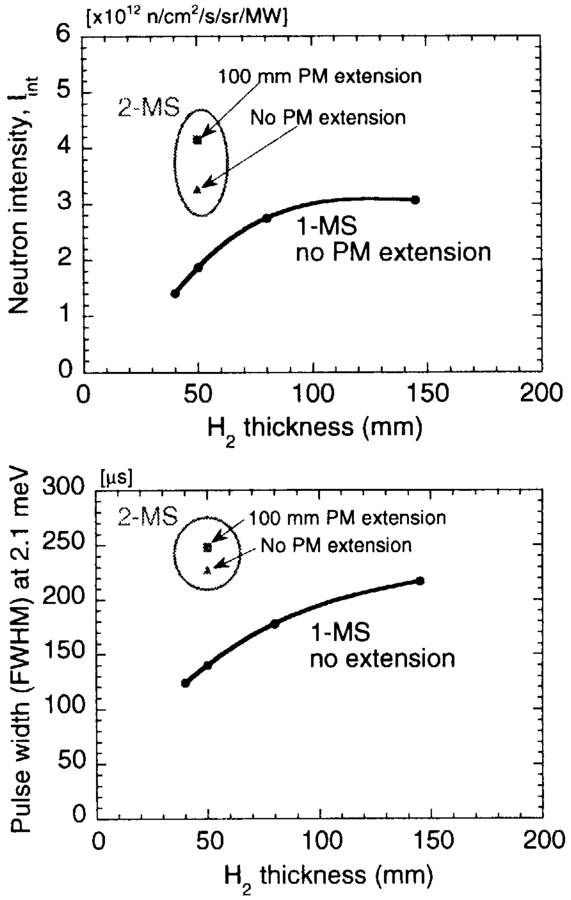

Fig. 3 The effects of H_2 thickness on neutron intensity and pulse width.

3.3 Premoderator extension

We studied the effect of the PM extension on I_{int}, FWHM and E_{dep} for the 2-MS of 50 mm H_2 and the 1-MS of 50 mm and 80 mm denoting 1-MS50 and 1-MS80, respectively. The effects of the PM extensions on I_{int} are shown in Fig.4. The effects are almost saturated at 150 mm extension in all moderator systems. At 150 mm extension, the I_{int} gain factors relative to the no extension case are 120%, 65% and 34% for the 1-MS50, 1-MS80 and 2-MS, respectively. The achieved I_{int} from the 1-MS50 are lower only by 5% compared with the maximum achieved value for the 2-MS. In addition, the I_{int} from the 1-MS80 are approximately 4% higher than the 2-MS with longer PM extensions. It was found that the 1-MS could provide higher or comparable I_{int} than the 2-MS due to the remarkable effects of PM extension.

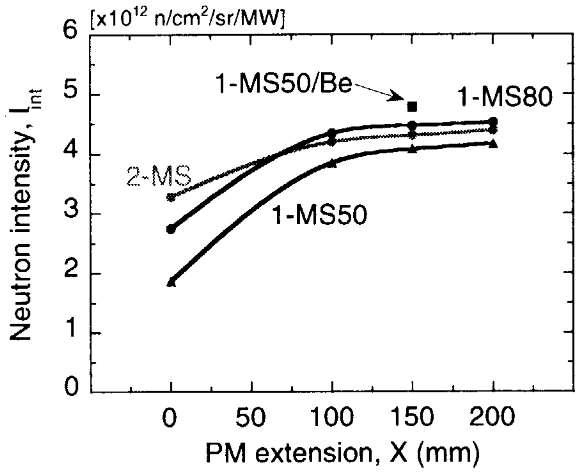

Fig. 4 The effects of PM extension on neutron intensities (I_{int}).

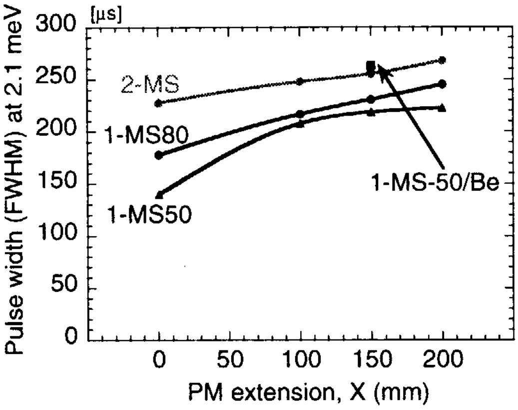

Fig. 5 The effects of PM extension on pulse widths (FWHM).

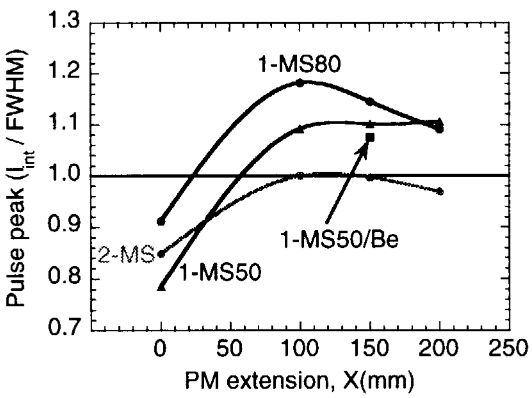

Fig. 6 The effects of PM extension on pulse peaks (I_{peak})

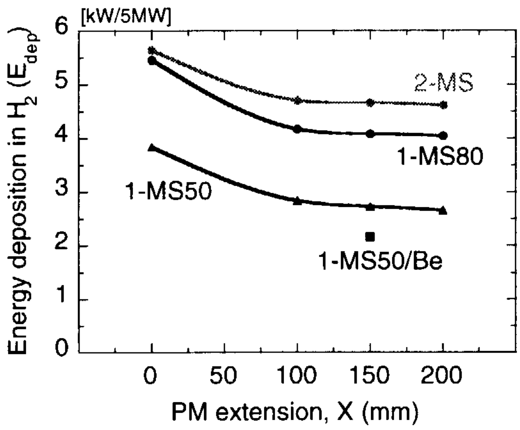

Fig. 7 The effects of PM extension on heat deposition in H_2 .

In Fig.5 the effects of PM extension on FWHM are shown. The FWHM gradually increases with the PM extension. However, those of the 1-MS50 and the 1-MS80 are narrower than the 2-MS in the whole extension range. Even at 150 mm, the FWHM is still narrower than the 2-MS by approximately 15%. The wider pulses for the 2-MS seem to be due to the larger effective thickness of H_2.

Figure 6 shows the effects of PM extension on I_{peak} derived by $I_{int}/FWHM$. As clearly seen in the figure the 1-MS80 gives the highest I_{peak} at 100 mm extension. The I_{peak} from all systems saturate or decrease with PM extensions longer than 100 mm due to the more increases of the FWHM than that of I_{int}.

The E_{dep} in H_2 moderator(s) are shown in Fig.7. They decreases with the PM extension and saturate at about 150 mm extension in all moderator systems. The saturated values are roughly proportional to the total volume of the moderators.

4 Comparison between lead and beryllium reflected system

For the discussion about reflector materials we performed a calculation in the Be reflected system with the same calculation model as the 1-MS50. An I_{int}, a FWHM, an I_{peak} and E_{dep} in Be system are also shown in Fig.4-7. The I_{int} from the Be system is higher than any other cases in the Pb system, However, the I_{peak} is smaller than the Be system with much wider FWHM and longer decay time as shown in Fig.4 and Fig.8.

We should note that the I_{int} can be estimated to increase by about 7% than the value for the Be system in Fig.4 as a result of the optimization study of PM extension in a Be system, although it has not finished yet.

5 Results

The I_{int} and the E_{dep} saturated at about 150 mm extension for all cases in the Pb system, however, the FWHM continued to increase. The I_{peak} saturated or decreased with PM extensions of longer than 100 mm. The 1-MS80 with 100 mm extension is the best if I_{int} and I_{peak} are more important, while the 1-MS50 with 150 mm extension was the best candidate if a lower E_{dep} and a narrower FWHM is important. In all cases of the Pb system, the 1-MS was better than the 2-MS.

The I_{int} in the Be system was higher than any other systems in the Pb system. However, the pulse characteristics were inferior to the Pb system.

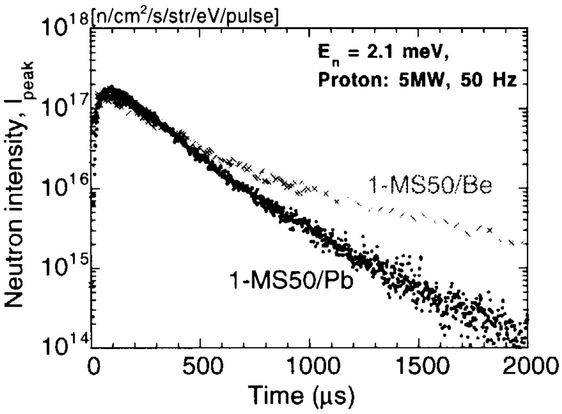

Fig. 8 The time distributions of neutron pulses in lead and beryllium reflected system.

6 Conclusion

The results of the present study have shown that a further increase of PM extension could compensate the intensity decrease due to the replacement of the 2-MS by the 1-MS with the improvement in pulse characteristics. Therefore, we came to a conclusion that the 2-MS should be replaced by the 1-MS not only from the neutronic point of view but also from the viewpoints of engineering feasibility and cost saving. There will be an additional merit in the 1-MS in terms of increasing the stability in the system operation.

Acknowledgement

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