Abstract. Experimental technique for measuring proton inelastic scattering with high resolution at forward angles including zero degrees have been developed. A good energy resolution of 20 keV with a scattering angle resolution of 0.5-0.9° has been obtained. Detailed analyses for obtaining $1^+$ strength distributions are in progress. Systematic studies of $M1$ strengths and their distributions are of much interest. From the study of Gamow-Teller strengths by $(p, n)$ reactions, it was claimed that the observed strengths were systematically smaller than the sum rule value. It is so-called Gamow-Teller quenching problem. Recent sophisticated measurements and analyses of $(p, n)$ reactions have shown that a large fraction of the missing strength is located in the continuum of up to 50 MeV [1]. It indicates that the main part of the “quenching” is caused by the mixing of the one-particle-one-hole states to two-particle-two-hole and higher configurations. As for the $M1$ strengths, systematic measurements of $(p, p')$ reactions have been performed at forward angles at Orsay and Saturne. They reported that quenching phenomena also occur for both isoscalar ($\Delta T = 0$) and isovector ($\Delta T = 1$) $M1$ strengths of $^{28}$Si, and later that almost no quenching was observed in $sd$-shell nuclei if the summed strengths for $\Delta T = 0$ and 1 were considered [2]. However, the measurement of cross sections at zero degrees was not feasible and even the data at forward angles suffered from much experimental background. Spin-parity and isospin assignment of each state was not satisfactory. Thus the systematic errors were large and the results were not conclusive.

Another concern is distribution of the fragmented $M1$ strengths. The $M1$ strengths of $^{48}$Ca are considered to have a simple shell model configuration. Actually most of the $M1$ strength is believed to be concentrating on a state at 10.22 MeV. Recently from studies using $(p, p')$ reactions it has been claimed that a considerable fraction of the strength is possibly fragmenting into many tiny states around the foot of the state at 10.22 MeV. The shape of the distribution is not easily explained by simple theoretical calculations. Our plan is to obtain high quality data.
at forward angles to identify the spin-parity of each state and accurate strength distribution of the fragmented strengths.

After developments on tuning high-resolution halo-free beams at the Research Center for Nuclear Physics, we have succeeded in measuring high-resolution proton inelastic scattering from targets up to \(^{64}\text{Ni}\) at \(E_p=295\) MeV and at scattering angles of 0, 2.5, and 4.5 degrees. The target thicknesses were 1-5 mg/cm\(^2\). The energy spread of the beam was as small as 40 keV by full width at half maximum. It corresponds to a beam spot size of 3 mm in the dispersive direction at the target, which sufficiently reduce the uncertainty of the solid angle of the spectrometer depending on the spot size. By applying dispersion matching technique, we achieved an excitation energy resolution of \(\leq 20\) keV.

We have used medium under-focus mode of the Grand Raiden spectrometer for the purpose of obtaining a reasonable scattering angle resolution in the vertical direction. A scattering angle resolution of 0.5 (0.9)\(^\circ\) have achieved at the lower (higher) excitation energy region. The ion optical parameter for the vertical scattering angle is very sensitive to the vertical beam position. For monitoring the vertical beam spot position we used another spectrometer LAS by measuring protons produced by quasi-free scattering at the target. From calibration data we could observe a perfect correlation between the origin of the vertical scattering angle and the vertical beam position monitored by the LAS. It was one of the key points for the good scattering angle resolution. The horizontal scattering angle resolution was as good as 0.15\(^\circ\). Experimental background events were subtracted by assuming their flat distribution in the vertical position at the virtual focal plane in the vertical direction. For details of the analysis, see Ref. 4.

A sample spectrum for \(^{28}\text{Si}\) target is shown in Fig. 1. We can see a beautiful spectrum being essentially free from background events in a wide excitation energy region of 5-25 MeV, with a good energy resolution of \(~20\) keV. Calibrations of scattering angle and solid angle are in progress. After obtaining angular distribution and spin-parity assignment of each peak, strength distributions will be obtained.

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