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A METHOD TO TUNE PULSE MAGNETS' WAVEFORMS

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Abstract

Pulse magnets are used in storage ring injection kickers. The waveform of the four kickers have strong relation with injection efficiency. A slightly offset of waveform may cause the four kickers mismatched, which would lead to storage beam loss and decrease injection efficiency. In order to define the peak value and timing of the half-sine waveform which has noises interfering diagnosis, a curve-fitting method was introduced to monitor and fine-tuning the waveform. The waveforms' data are also archived for reference in case of replacing power supplies. By using this method, it helps to retain a consistent injection efficiency after the power supplies maintenance or replacement.

INTRODUCTION

The accelerator complex of Taiwan Photon Source (TPS) project consists of a 150 MeV linac, 3 GeV booster, and a 3 GeV storage ring. Pulsed magnets are used for beam injection into and extraction out of the booster and storage ring. The layout of TPS injection scheme and its associated geometric arrangement are illustrated in Fig. 1. There are three septum power supplies with the same configuration and four identical units of kicker fabricated for TPS project [1]. It's crucial to match shape of these kickers' waveforms for top-up operation or it will inhibit users from data acquisition application. The power supplies would degrade with time or sometimes broke down for replacement. To ensure the consistent performance of the kickers and septum, the peak values of the half-sine waveforms were introduced as an indicator to tune and monitor them. However, due to the alias of the waveform, a curve-fitting method was implemented to pinpoint the peak values.

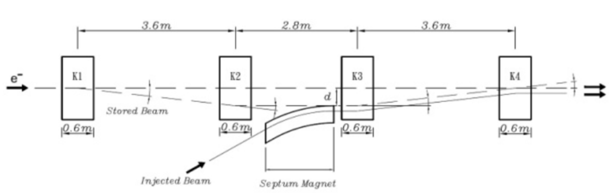

Figure 1: Layout of TPS injection scheme and the related parameters.

KICKER & SEPTUM POWER SUPPLY

To guide the electron beam aiming toward the designated space coordinates and arriving at the proper entrance of the transfer line, the septum are arranged at upstream of injection kicker and downstream of extraction kicker. The half-sine pulses of the kickers are illustrated in Fig. 2. In real situations, the pulses are not perfect half-sine curves. Once the pulses were inspected in a small scale or zoomed in, the noises and alias of the signals inhibit us from determining the peak values of the pulses (Fig. 2 and 3). To analyse the signals, we use MATLAB curve-fitting tool to find curves which have the smallest SSE (Error Sum of Squares) with the original data. The peak position values were then determined as an indicator to tune the pulses.

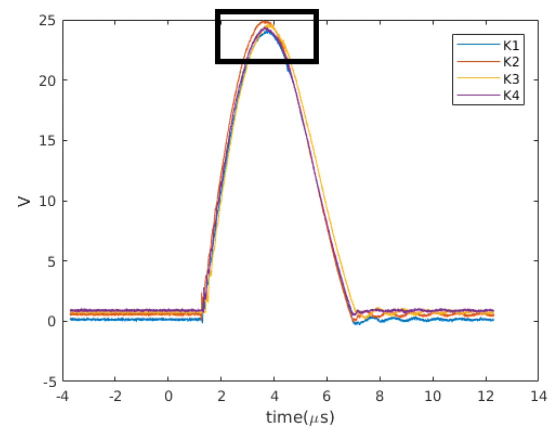

Figure 2: The aligned pulses of four units kicker power supplies.

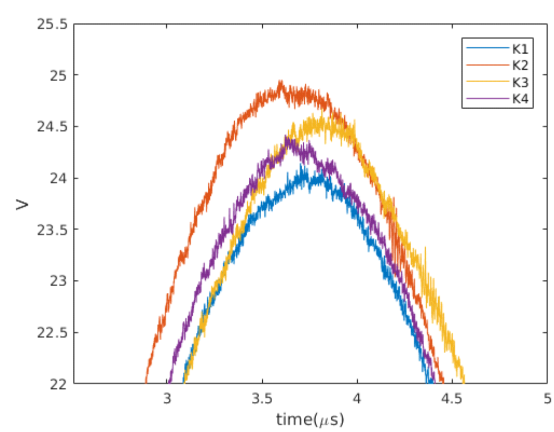

Figure 3: Zoom into the black square area of Fig. 2.

CURVE-FITTING TOOL

Since the pulses are designed as half sine, 'Sum of Sine functions' model was firstly put into tested. The sum of sines model fits periodic functions, and is given by:

$$. (x) = a_1 * \sin(b_1 x + c_1)\,\bar{A} \cdots + a_n \sin(b_n x + c_n) \quad (1)$$

where a is the amplitude, b is the frequency, and c is the phase constant for each sine wave term. n is the number of terms in the series and $1 \le n \le 8$. This equation is closely related to the Fourier series described in Fourier Series. The main difference is that the sum of sines equa-

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tion includes the phase constant, and does not include a constant (intercept) term. The fitting results (Fig. 4) shows that the goodness of fit changes with n. There are four factors to determine the goodness of fit: [2]

- The sum of squares due to error (SSE)
- R-square
- Adjusted R-square
- Root mean squared error (RMSE)

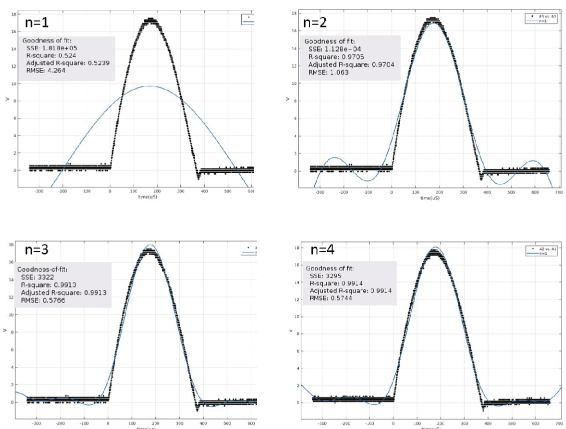

Figure 4: Fitting results of different number of terms n=1~4.

Table 1: Goodness of fit with Different Number of Terms n

	SSE	R-square	Adj. R-square	RMSE
n=1	$1.8*10^5$	0.524	0.523	4.264
n=2	$1.1*10^4$	0.971	0.970	1.063
n=3	3322	0.9913	0.9913	0.5766
n=4	3295	0.9914	0.9914	0.5744

Sum of Squares Due to Error(SSE)

This statistic measures the total deviation of the response values from the fit to the response values. It is also called the summed square of residuals and is usually labeled as SSE.

$$SSE = \sum_{i=1}^{n} w_i (y_i - \hat{y}_i)^2 \tag{2}$$

R-Square

R-square is defined as the ratio of the sum of squares of the regression (SSR) and the total sum of squares (SST). SSR is defined as

$$SSR = \sum_{i=1}^{n} w_i (\hat{y}_i - \bar{y})^2 \tag{3}$$

SST is also called the sum of squares about the mean, and is defined as

$$SST = \sum_{i=1}^{n} w_i (y_i - \bar{y})^2 \tag{4}$$

where SST = SSR + SSE. Given these definitions, R-square is expressed as

$$R - \bar{A}quare = \frac{SSR}{SST} = 1 - \frac{SSE}{SST} \tag{5}$$

R-square can take on any value between 0 and 1, with a value closer to 1 indicating that a greater proportion of variance is accounted for by the model.

Degrees of Freedom Adjusted R-Square

The residual degrees of freedom is defined as the number of response values n minus the number of fitted coefficients m estimated from the response values.

$$\bar{A} = n - m \tag{6}$$

v indicates the number of independent pieces of information involving the n data points that are required to calculate the sum of squares.

The adjusted R-square statistic is generally the best indicator of the fit quality when you compare two models that are nested — that is, a series of models each of which adds additional coefficients to the previous model.

$$\text{adjusted R} - \text{square} = 1 - \frac{SSE(\bar{A}\bar{A}\bar{A})}{SST(\bar{A})} \tag{7}$$

Root Mean Squared Error(RMSE)

This statistic is also known as the fit standard error and the standard error of the regression. It is an estimate of the standard deviation of the random component in the data, and is defined as

$$\text{RMSE} = \text{s} = \sqrt{MSE} \tag{8}$$

where MSE is the mean square error or the residual mean square

$$\text{MSE} = \frac{SSE}{v} \tag{9}$$

From the fitting results (Table 1), the fitting-curve can be considered as a good fit when the number of terms n=3. The same fitting method were applied to all pulse magnet power supplies. A GUI had been developed to monitor and record the peak position values.

MONITOR AND RECORD GUI

All pulse magnets' waveforms and their fitting results were displayed in GUIs. The data will be updated during injection cycles and saved hourly as reference. The peak position values, SSE and FWHM (Full width at half maximum) of the fitting results were marked on the plots, which allows operators to keep track on the waveform change (Fig. 5 and 6).

We are developing an auto-tuning system, which will automatically scan through different relative time delay to

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find the best shape-matching positions for the pulse magnets. It will need the database of currently developed fitting tool. We believe it will improve injection efficiency and reduce injection disturbance.

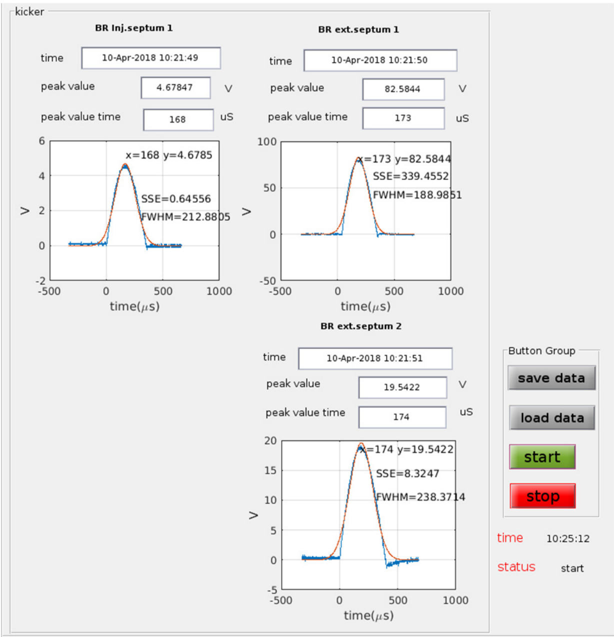

Figure 5: booster septum pulse monitor GUI.

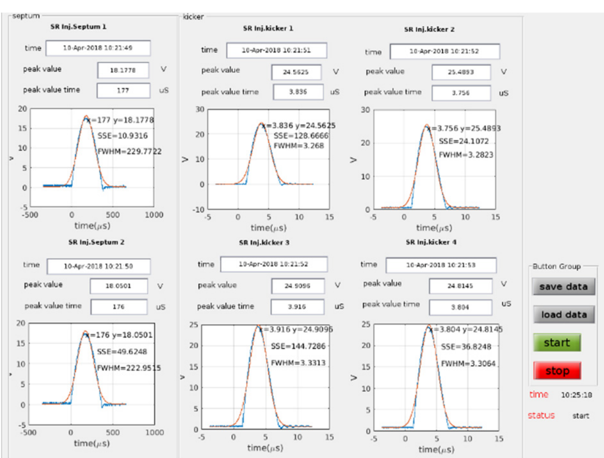

Figure 6: storage ring injection pulse monitor GUI.

CONCLUSION

In order to define the peak value and timing of the half-sine waveform which has noises and alias interfering diagnosis, a curve-fitting tool is developed as a method to tune pulse magnets matching. Different fitting models were put into test to find the best fit. The data will be updated during injection cycles and saved hourly as reference. An auto-tuning system is in development to find the best matching positions for the pulse magnets.

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[1] C.S. Fann, K.L. Tsai, C.L. Chen, A.P. Lee, S.Y. Hsu, K.T. Hsu and K.K. Lin, “The pulsed power supply systems for TPS project”, in *Proc. IPAC’13*, Shanghai, China, May 2013, pp. 771-773.

[2] The MathWorks, Inc., “Evaluating Goodness of Fit”, https://www.mathworks.com/help/curvefit/evaluating-goodness-of-fit.html