

# GROUND MOTION STUDY AND THE RELATED EFFECTS ON THE J-PARC

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## Abstract

The power spectrum density, coherence and cross-spectrum density of the ground motion in the J-PARC site are studied to get the guideline of the beam control systems. J-PARC consists of a 400MeV linac, a 3GeV Rapid-cycling synchrotron (RCS) and a 50GeV synchrotron (MR). MR provides a beam current of 15  $\mu A$  with a period of 3sec to either the nuclear physics experimental area or the neutrino production target. MR is a very high beam power machine, so its optimum beam loss must be kept fewer than 0.01% of an accelerated beam in order to decrease the radiation damage of accelerator components and to get easy accessibility to them. From the point of view of beam loss, we give some detailed discussion about the relation between the MR operation and the ground motion using the observed data.

## INTRODUCTION

Although a stable ground is preferable for large scale and high intensity accelerator to get good beam operation quality, J-PARC site is located on complex geological structures and is very close to the Pacific Ocean. Since they have started the construction without detailed ground motion study, it is very important to understand the characteristics of the ground motion for a prediction of the beam loss caused by emittance blow up induced by the space charge and related instabilities.

In this paper, we report the results of the ground motion measurement using six servo type velocity meters (STS-2 of Streckeisen, Switzerland) and ten water tube levelling meters (JS-50 of Jidohseigy Giken Co. Ltd., Japan). The former equipment was used to obtain the ground motion signals between 0.005Hz and 50Hz frequency band and the latter to obtain the frequency range less than 1mHz. We set the both type sensors at regular intervals of 20 meters.

## DESCRIPTION OF GROUND MOTION

Many measurements on the ground motion were made for several accelerator sites and their related sites, since the special interest of accelerator physicists. Any alignment errors cause an orbit distortion and which leads to reduction of the dynamic aperture of the machine. An extreme situation is emittance growth of the accelerating beam. Slow ground motions which frequency components are less than characteristic frequencies of the accelerator have been usually considered as not having serious effect on machine operation, assuming complete space and time coherence of the ground motion. This assumption, however, not exactly works out as a result of ATL model [1]. The ground motion caused by daily or seasonal

variation of ground temperature, groundwater level variation, atmospheric pressure variation and earth tides have a large correlation length. The residual part of these variations, however, becomes inelastic component of the ground motion and loses the correlation since the source of the motion is removed. The spectrum of this ground motion, excluding characteristic spectra, is empirically given as,

$$P(f) = \frac{K}{4\pi^2 f^2 (f_0^2 + f^2)} \quad (1)$$

where  $P(f)$  is a power spectrum in  $m^2/Hz$ ,  $K$  is constant and  $f$  is frequency in Hz. The constant  $f_0$  is depends on geological features and changes from 0.1Hz to 0.01Hz [2]. In our experiments,  $f_0$  is about 0.1Hz for the quiet hard rock region, and about 0.01 Hz for the noisy weak ground region.

The ATL model can be formulated using an auto-correlation function  $\langle y(t+\tau)y(t) \rangle$ , as

$$\begin{aligned} \Delta y(\tau)^2 &= 2 \langle y(t)^2 \rangle - 2 \langle y(t+\tau)y(t) \rangle \\ &= A \cdot L \cdot \tau. \end{aligned} \quad (2)$$

Here,  $\langle X \rangle$  means an ensemble average. Using the definition of a power spectral function,

$$P(f) = \int_{-\infty}^{\infty} \langle y(t+\tau)y(t) \rangle e^{-2\pi i f \tau} d\tau, \quad (3)$$

then equation (2) becomes,

$$A \cdot L \cdot \tau = 4 \int_{-\infty}^{\infty} P(f) \sin^2(\pi f \tau) df. \quad (4)$$

If we assume that the power spectrum is proportional to the inverse of squared frequency ( $f \ll f_0$ ), we can carry out integration in the right hand side of the equation (4),

$$4 \int_{-\infty}^{\infty} P(f) \sin^2(\pi f \tau) df = K \cdot \tau. \quad (5)$$

Putting this result into the equation (1), we find the power spectral function of ATL model as,

$$P(f) = \frac{A \cdot L}{4\pi^2 f^2}. \quad (6)$$

In the actual experiment, we have to introduce a cutoff frequency  $1/\tau_{max}$  in the power spectral function,

$$P(f) = \frac{K}{4\pi^2 f^2 + (1/\tau_{max})^2}, \quad (7)$$

integration in the equation (5) becomes,

$$4 \int_{-\infty}^{\infty} P(f) \sin^2(\pi f \tau) df = K \tau_{max} (1 - e^{-\tau/\tau_{max}}). \quad (8)$$

In other words, the ATL model will be replaced by,

$$\Delta y(\tau)^2 = A \cdot L \cdot \tau_{max} (1 - e^{-\tau/\tau_{max}}). \quad (9)$$

Recently, many accelerator physicists use ATL model for their accelerator simulation because of simplification of the calculation. But we have to take account of applicable limitations in the light of coherency of the ground motion spectrum. The parameters of  $f_0$  and  $K$  have

strong dependency on the site. Then, if we want a good simulation of the related accelerator, we must formulate an optics including the equation (1) and coherency of the real site. In table 1, we present 10 examples of *A*-value as a guide of consideration of the ground motion in Japan [3].

Table 1: ATL coefficient in Japan

No	Site Name	A (nm <sup>2</sup> /m/sec)	Geology of the Place
1	Tunnel of KEKB	4.0E+01	Clay and Gravel
2	Rokkoh-1	3.6E+01	Granite (near Fault)
3	Rokkoh-2	3.3E+01	Granite
4	Miyazaki	1.5E+01	Diorite
5	SPring8	8.0E-01	Granite
6	Kamaishi-1	1.4E-01	Granite (Crack and Water)
7	Kamaishi-2	5.7E-02	Granite
8	Sazare	5.0E-02	Green Schist
9	Esashi-1	5.7E-03	Granite (Floating Stone)
10	Esashi-2	2.0E-03	Granite

### GROUND MOTION AT J-PARC

#### Observation Using STS-2

The ground motion in the seismic frequency region usually shows complex power spectrum. The spectrum is composed of smooth spectrum as  $k/f^n$ , ocean swell around 0.2Hz, crustal resonance around 3Hz and noises of human activity in the frequency range 1 to 100Hz. Fig. 1 shows typical power spectrum densities of the ground motion being observed on the different geological conditions.

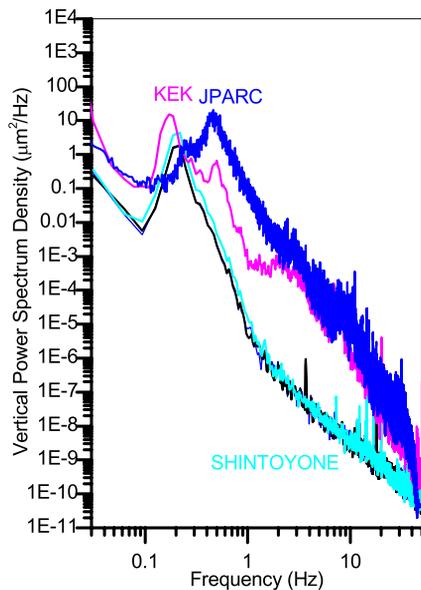


Figure 1: Power spectrum densities obtained on the different geological conditions.

Shintoyone is a big underground hydroelectric plant (1,125,000kW at maximum), but we can find that the site

is very quiet, except some narrow band mechanical noises originated in the plant, since the site is located in the granite bedrock region [4]. To the contrary, KEK and J-PARC sites are very noisy in the frequency region higher than 0.3Hz.

We selected six measuring points in the straight section of the MR tunnel paralleling to the coastline and STS-2's were set at intervals of 20 meters [5]. Those intervals were selected to understand the influence of the ground motion to the circulated beam, since the minimum interval is a little shorter than the betatron wavelength. The correlation between distant measuring points is given by a cross-spectrum, and the absolute value of the normalised cross-spectrum is coherence. Observations of the coherence as a function of distance are very important, since geological conditions are very different from position to position and the complicated surface of the soft mudstone bed in the J-PARC site. Fig. 2 shows coherences between P3K and each other sensor. Observed coherences grow worse as a function of distances.

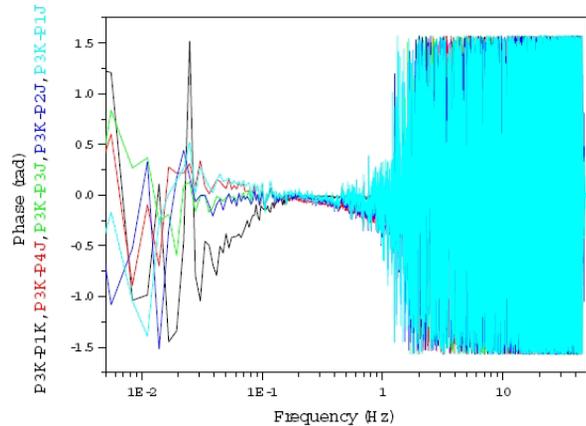


Figure 2: Coherences between two sensors (P3K-P2K, P3K-P4J, P3K-P3J, P3K-P2J and P3K-P1J). The symbols are the same as Ref. [5].

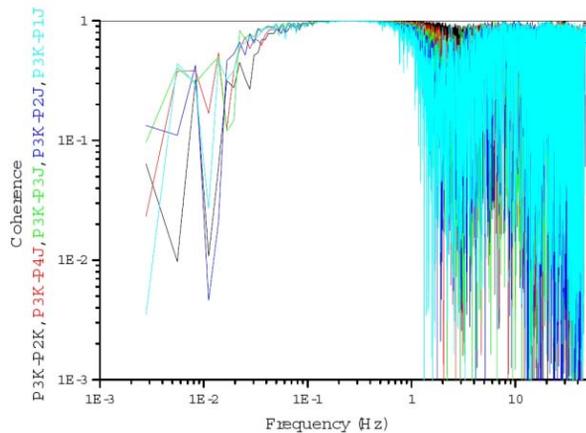


Figure 3: Phases between two sensors (P3K-P2K, P3K-P4J, P3K-P3J, P3K-P2J and P3K-P1J).

Fig. 3 shows the observed phase differences between P3K and each other sensor. Observed phases are chaotic in the frequency range higher than 1Hz and show complex fluctuations in the frequency range less than 0.1Hz. We

describe the detailed power spectrum density of J-PARC site in another contribution of this conference [5].

### Observation Using JS-50

We set ten water tube levelling meters (JS-50) in the tunnel to obtain the ground motion signals for their frequency range less than 1mHz and to get information about their correlation functions. Fig. 4 shows one of the power spectrum density and the integrated one.

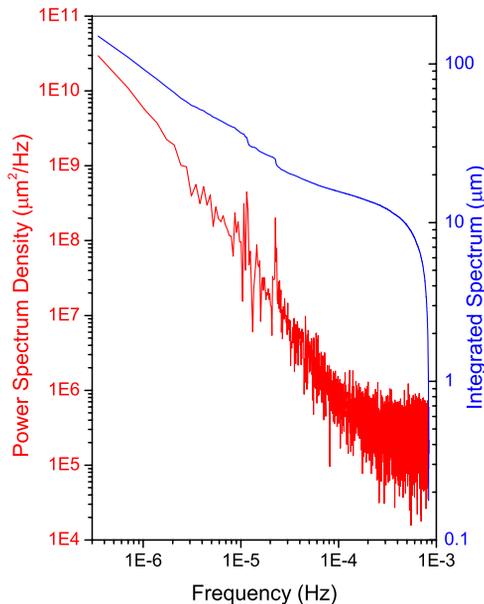


Figure 4: Typical power spectrum density and integrated spectrum obtained by JS-50. Eminent spectrum components around 1E-5Hz regions of frequency are corresponding to the ocean-tide.

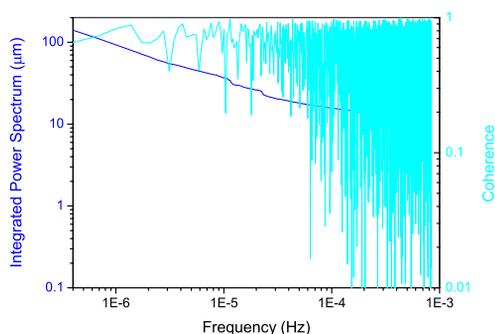


Figure 5: Typical integrated spectrum and coherence between the two positions at a distance of 40m.

The present coherence results, as shown in figs. 5 and 6, are very different in comparison with the results of hard rock region [3]. The present coherence shows very bad even if we restricted it in the narrow frequency region of

the ocean tide, and the phase differences between the two points at a distance 40m show disorderly behaviour.

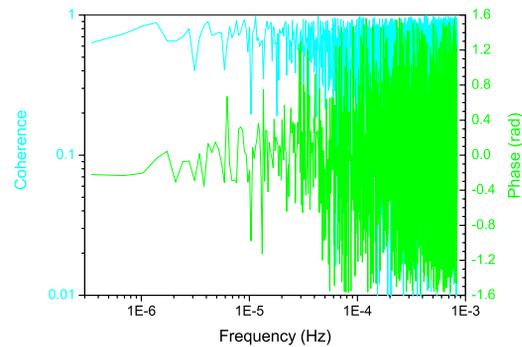


Figure 6: Phase difference and the coherence between the two positions at a distance of 40m.

We can get an *ATL* coefficient for the J-PARC site using the present results as it is  $A=1.3E3nm^2/sec/m$  which is about 33 times larger than that of KEK as shown in Table 1. This value is a critical value for COD correction.

Recently a simulation study for space charge effect was started in order to speculate the beam loss in the injection porch of the MR [6]. The simulation shows a large emittance growth at the relatively small beam power being 1.8kW/ bunch, though it excludes the effect of the misalignment for the Q-magnets.

### SUMMARY

The site is located on the complex geological structures, but they have started the construction without detailed ground motion study. This lack of the first care gave wrong guideline for the tunnel construction method of MR. As a result of our ground motion studies, we can show that the J-PARC site is very critical site for the large accelerator construction. Detailed simulation is required including COD and the present observed phenomena.

### REFERENCES

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