

# Development of Stretched wire measurement bench at IDDL, DAVV Indore

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**Abstract:** A stretched wire magnetic measurement bench is under development at IDDL, DAVV, Indore. In this method a multistrend wire consisting of  $N$  turns is stretched inside the undulator to measure the field integrals of the undulators. The wire moved with constant velocity of translation measures the first integral of the undulator field. The cross motion of the wire at the undulator ends measures the second field integral. The measurement accuracy depends on the wire conditions and material properties. In this paper we follow an analytical approach to find the voltage fluctuations due to wire vibrations during the field measurement. It is shown that the voltage fluctuations depend on undulator gap, magnitude of the impulse on the wire. The mass density and the length of the wire also cause sizeable voltage fluctuations. The analytical derived expression is analysed to optimize system parameters for minimum errors during the measurement.

## 1. Introduction

The IDL Laboratory at DAVV, Indore is in the stage of fabrication of different types of undulator like 1m long PPM undulator, 0.5m hybride undulator. For the perfect fabrication of undulator a precise measurement procedure is mandatory to decide its suitability for FEL experiments. The IDL Laboratory has developed a Hall Probe Bench[1,2] and a Pulsed Wire Bench[1,2] for the undulator measurement. The Hall probe method for magnetic field measurement is a point to point measuring system. In this method the probe is moved along the undulator axis to measure the field at each point of the undulator axis. By the integration of the field we get the first and second field integral of the undulator. The first and second field integral are the quantities which gives the angle and electron trajectory along the length of the undulator. In quality undulators, both these quantities hold to a minimum value. In the Pulsed wire method a wire is stretched along the length of the undulator axis. An appropriate pulse is provided to the wire and because of field of the undulator mechanical vibrations are produced in the wire and these vibrations directly gives the first and second field integral.

Now a days in the laboratory development of stretched wire bench[3-5] is in progress. In this method the field integrals are measured by integrating the voltage induced during the motion of the stretched wire inside the undulator. By moving the wire with the constant speed, induced voltage is proportional to first integral of the undulator field and the cross motion of the wire ends induces the voltage proportional to second integral of the field. In this paper we are describing the details of experimental setup and analytical approach to find the voltage fluctuations due to wire vibrations during the field measurement.



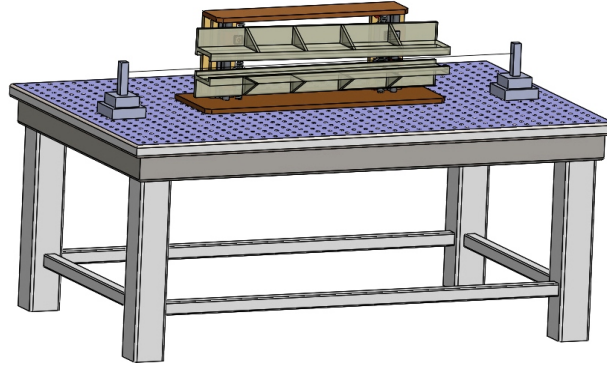


Fig 1. Stretched wire bench.

## 2. Details of experimental setup:

The details of components being used in the stretched wire bench is describing in this section. The measuring setup is under development stage which consists of two XYZ translation stages. The XY stages will be used for positioning and translating the stretch wire. The stages being used are Holmarc make model no. LMS-100-100. These stages are driven by motion controller. The travel range is upto 50mm. The Z stages are manually driven Holmarc make model no. TS-120-MU-10-01 and will be used for stretching the wire to reduce sag. The induced voltage will be measured by 2182A Keithley nanovoltmeter. It has the accuracy of typically just 15nVp-p noise at 1s response time, 45-50nV p-p noise at 60ms.

The XY stages and the voltmeter will be interfaced to a PC with LABVIEW software by National Instruments. Titanium, Cu-Be, Tungsten wire of diameter 125 $\mu$ m will be used for the measurements. The entire stretched wire setup with the undulator will be supported on a Honeycomb table top vibration isolation structure. The pneumatic vibration isolation system is a steel structure framework for supporting the honeycomb breadboard nonmagnetic table top, isolating the tabletop from vertical and horizontal disturbances. The physical dimension of the table top is 2000 mm  $\times$  1200 mm  $\times$  200 mm .

## 3. Theory for wire vibration induced field integral:

If the wire is moved with a constant velocity of translation in the transverse direction, we find an induced voltage as,

$$V_1 = \frac{d}{dt} \iint B_y dz dx = v I_y \quad (1)$$

Where  $v = dx/dt$  is the velocity of translation of the wire in  $x$  -direction. The second field integral is measured with cross motion of the ends i.e. by moving the ends of the wire in opposite directions and getting the induced voltage as,

$$V_2 = \frac{d}{dt} \iint B_y dz dx = \frac{2v}{L} I_y \quad (2)$$

Vibrations in the wire cause and introduce fluctuations in integral field measurements. In order to determine the effects of these vibrations , we consider a wire of length  $L$  with fixed ends at  $z=0$  and  $z=L$  under a tension  $T$  . Using the impulse solution [4] we can write the Eq(1) as

$$V_1(t) = v \int_0^L B_u dz + \int_0^L B_u \sum_n \frac{2I}{\mu L} \sin(\alpha_n z) \cos(\omega_n t) dz \quad (3)$$

In Eq.(3) is obtained in the approximation that the undulator field does not change too much in the transverse direction. The undulator field is represented as,  $B_u = \bar{y}B_0 \sin(k_u z)$ ,  $k_u = 2\pi / \lambda_u$ ,  $\lambda_u$  is the undulator period. Eq.(3) can be expressed as,

$$V_1(t) = vI_y + \frac{IB_0}{\mu L} \sum_n I_n \sin(\alpha_n \xi) \cos(\omega_n t) \quad (4)$$

$$I_n = \int_0^L 2 \sin(k_u z) \sin(\alpha_n z) dz \quad (5)$$

Eq.(4) is evaluated by averaging  $V(t)$  for a sufficient time in order to have the translation motion in the transverse direction in order of few  $mm$ , thus remaining in the approximation that the undulator field is independent of  $x$  and solving the integral in Eq.(5)  $\bar{t} = \Delta t C_s / L$ , using  $\cos n\pi = (-1)^n$ ,  $\xi = L/2$ ,  $\sin(\alpha_n \xi) = 1$  for  $n = \text{odd}$ ,  $\xi = L/2$ ,  $\sin(\alpha_n \xi) = 0$  for  $n = \text{even}$ , we rewrite Eq.(4) as,

$$\int_0^{\Delta t} V_1(t) dt = \Delta x I_y + \frac{2IB_0 L}{\mu C_s} \sum_{n=\text{odd}} \frac{\sin(k_u L)}{(n^2 \pi^2 - k_u^2 L^2)} \sin(n\pi \bar{t}) \quad (6)$$

The effects of the wire vibrations on second field integral can be estimated following a similar procedure. The voltage induced can be read as, Substituting and solving the Eq.(5) using the same quantities as used for Eq(6), we get

$$\int_0^{\Delta t} V_2(t) dt = \frac{2\Delta x}{L} I_y + 2 \sum_{n=\text{odd}} \frac{2IB_0 L}{\mu C_s} \frac{\sin(k_u L)}{(n^2 \pi^2 - k_u^2 L^2)} \sin(n\pi \bar{t}) \quad (7)$$

#### 4. Results and discussions:

Fig. 1 shows the design of stretched wire bench. In this paper, we have followed an analytic approach to estimate the voltage fluctuations due to wire vibrations in a stretched wire measuring bench. Denoting

$$b_n = \frac{2IB_0 L}{\mu C_s} \frac{\sin(k_u L)}{(n^2 \pi^2 - k_u^2 L^2)} \sin(n\pi \bar{t})$$

In Fig. 2, we plot error for several values of impulse in the range from  $2.0 \times 10^{-7}$  to  $2.0 \times 10^{-1}$  N-s. For  $I = 2 \times 10^{-7}$  N-sec,  $\Delta t = 5$  sec,  $\mu = 4.14 \times 10^{-5}$  Kg/m,  $T = 2.5$  N,  $C_s = 245.5$  m/sec. For example consider an undulator with  $\lambda_u = 50$  mm,  $N = 20$ . The plot shows one important feature of the effects of the wire vibrations. The wire vibrations contains several modes of vibrations. Whenever the wire resonant frequency corresponding to a particular mode equals the undulator frequency ( $\omega_n = \omega_u$ ), the peak value of the wire oscillations increases and brings a large fluctuations in voltage recording causing a large error. From Fig.(2), It is seen that it corresponds to the wire length i.e  $l = L_u + n\lambda_u/2$  where  $n$  is an odd number i.e 1,3,5,.....  $L_u = N\lambda_u$  is the undulator length. For our system it occurs at 1025 mm, 1075 mm. Fig 3, 4 and 5, we calculate the effects of the wire vibrations on the induced voltage for different values of impulse, peak magnetic field and tension respectively. Where we define  $\bar{V}_1(t) = \int_0^{\Delta t} V_1(t) dt$ . For the parameters of study there is a voltage fluctuation of 0.3 to 5 nVoltssec.

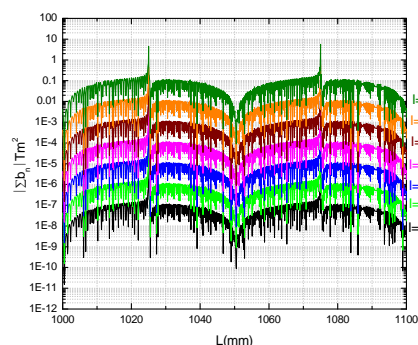


Fig 2 Integrated voltage errors versus wire length with several impulse magnitudes

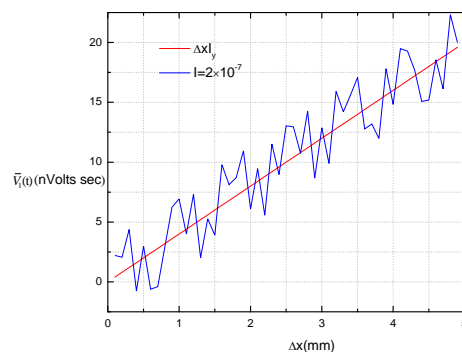


Fig. 3 Integrated voltage versus transverse wire displacement.

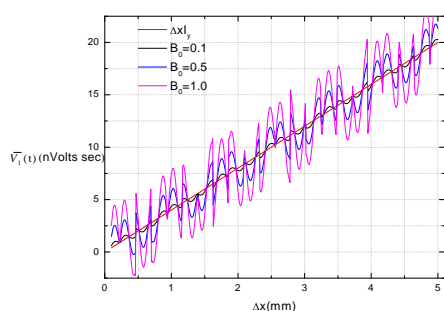


Fig. 4 Integrated voltage versus transverse wire displacement.

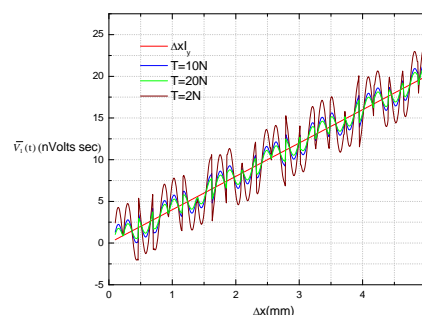


Fig. 5 Integrated voltage versus transverse wire displacement.

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### References

- [1] Sharma G, Gehlot M, Mishra G 2014 *World Scientific Journals* **3** 1450001
- [2] Sharma G, Mishra G and Gehlot M 2016 *Measurement* **82** 334
- [3] Gehlot M, Mishra G (Communicated 2016 ) *Nuclear Instruments and Meth.s in Phy. Re.s A*
- [4] Ciocci F, Dattoli G and Sabia E 2006 *SPARC-FEL-06/001*
- [5] Zangrando D and Walker R P 1996 *Nuclear Instruments and Meth.s in Phy. Re.s A* **376** 275