Vibrating Wire Monitor
VWM-005

User's Manual

This document refers to the VMW-005 5-wire Vibrating Wire Monitor delivered to Argonne National Laboratory in 2007 to measure the profile of photon beams on the Advanced Light Source. The APS scientist who evaluated it is Glenn Decker.

The electronics circuits and chassis described in this User's Manual are prototypes now replaced by modular electronics. The new electronics operate on the same principle for frequency measurement. Their differences from the prototype are:

- Front-end VWM placed near the sensor supporting two wires each are powered via a long (up to 50m) cable to the VWM chassis.
- A VWM chassis controls up to 8 front-ends, i.e. 16 wires, providing data readout via USB.

2007

HTM Reetz GmbH, Berlin, Germany
In cooperation with Yerevan Physics Institute, Yerevan, Armenia

Vibrating Wire Monitor
VWM-005

5 Wire Vibrating Wire Monitor

Specifications

SENSOR

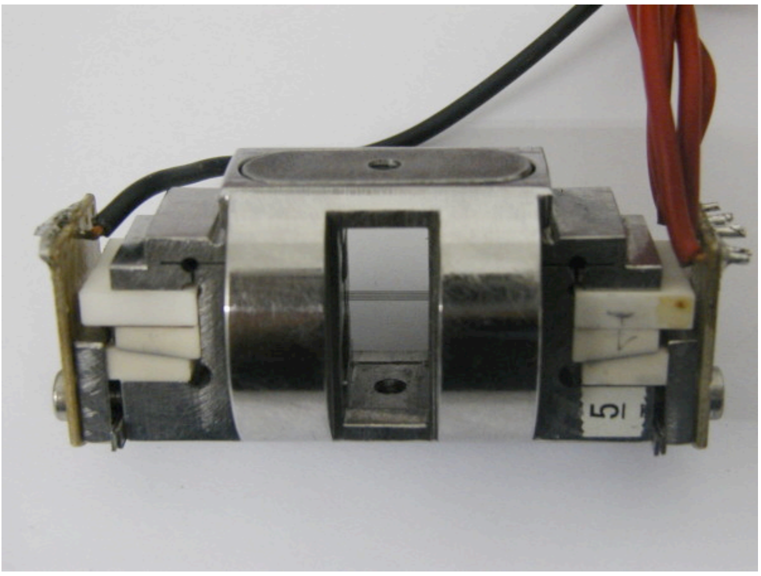

Fig. 1. VWM005 Sensor.

VWM005 Sensor Design Features

- 5 stainless steel wires of 0.1 mm diameter and 36 mm length, specially thermally treated;
- The distance between wires 0.5 mm;
- Area of wire exposure is 8 mm around the center;
- The pickup can be rotated around the central wire axis;
- Maximal rotation angle from plane containing wires is 45^0;
- At maximal rotation angle the vertical aperture of pickup window is 2.5 mm; the vertical offset between projections of the wires on the orthogonal plane is 0.35 mm;
- Less angle of rotation leads to less offsets between the projections.
- Aperure of VWM - 8mm (along the wires) x 6 mm (orthogonal)

Electromechanical parameters of VWM005

— Initial frequencies at room temperature are in range	4000-9000 Hz;
— Operating range of frequencies shifts from the initial frequency	0-1000 Hz;
— Resolution	0.01 Hz;
— Accuracy in one-hour interval	± 0.01 Hz;
— Accuracy in 24-hour interval	± 0.04 Hz;
— Response time	0.26 s;
— VWM output signal noise at 10 Hz	0.01 Hz/Rt(Hz)

Thermal characteristics of VWM005

Thermal characteristics of VWM005 are defined by the factor of frequency dependence on mean temperature of the wire overheating - 40.2 Hz/K at frequency 4200 Hz.

— Operation range of wire overheating	0-25 K;
— Wire temperature resolution	0.00025 K;
— Wire temperature accuracy in 1-hour interval measurement	± 0.00025 K;
— Wire temperature accuracy in 24-hour interval measurement	± 0.001 K;

Power characteristics of VWM005

Power characteristics of *VWM005* are determined by the factor of frequency dependence on the power deposited on the wire in the form of the heat at the interaction of photon beam with the wire material in air- 9.3 Hz/mW.

— Operational range of deposited power	0-100 mW;
— Resolution of deposited power	1 μW;
— Resolution of deposited power in 1-hour interval operation	± 1 μW;
— Resolution of deposited power in 24-hour interval operation	± 4.3 μW;
— Nonlinearity of the pickup in operational range of deposited power	0.01 %.
— ΔTmean/ΔQ = 0.23 K/mW	

ELECTRONIC UNIT

Fig. 2. VWM005 Electronic Unit.

Electronic unit contains the electronic plates for measurement of frequencies and their transfer. Electronic unit is to be line supplied 110 to 230 VAC 60/50 Hz Beside the net connector It also has a 8-pin connector for sensor, a SUBD 9 pin connector for data transfer in RS422 standard, 5 LEDs for each wire, 2 small LEDs indicating data transfer to or from the unit. 5 larger LEDs blink when the data from corresponding wire of the sensor is transferred. Small green LED blinks when all data in current sampling cycle are transferred. Small red LED blinks if some commands are transferred to electronic unit.

The sensor is connected with the electronic unit with a cable of length about 1 m.

It is strongly recommended to provide possibility of eletronic unit remote switching on/off (for intrinsic microcontrollers reset).

MOUNTING

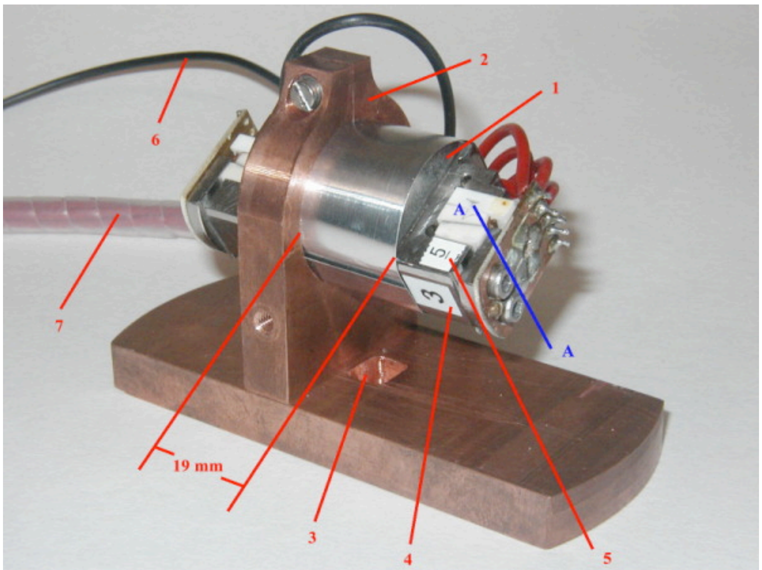

Fig. 3. VWM005 Mounting.

The sensor is mounted on a copper support for better thermal coupling with the flange on which it will be installed. The pickup can be turned around the central wire (the axis of symmetry of the cylindrical pickup). The wires are shifted along the line AA. For better correspondence with the feed opening on the horizontal plate (3 on the figure) of the support the distance between the face of the pickup (1) and the surface of the vertical plate (2) must be 19 mm. Also the number of the sensor (4) and numbers of the first and fifth (5) are marked. For convenience of disassemble on one side of the sensor all wires are connected together (6), and there is a possibility of disconnection of the common wire near the electronic block. Other wires are assembled in a harness (7).

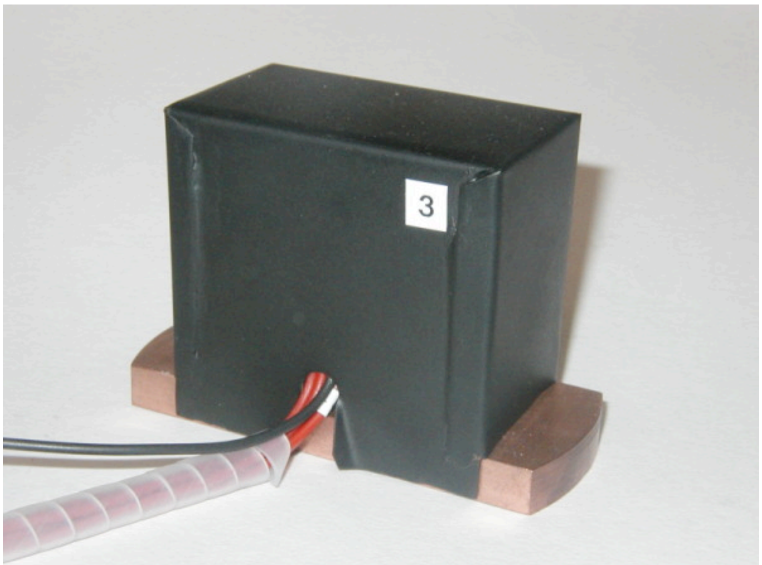

Fig. 4. VWM005 Sensor in Box.

Characteristics of measured photon beams depending on energy of photons

The beam of photons of energy ε passes through the vibrating wire heats the wire. Table presents the attenuation coefficients (μ_{en}, mm^{-1}) of the energy deposition by photons with different energies. The next column (l_p, mm) presents the characteristic length of photon beam penetration in wire material. The next columns (ΔP, ph/s/mm2) presents the *VWM005* resolution to the photon beam flux density. In the last column (MaxP, ph/s/mm^2) the maximal photon beam flux density is presented.

ε , eV	μ_{en}, mm^{-1}	l_p, mm	ΔP, ph/s/mm^2	MaxP, ph/s/mm^2
1.0E+03	6927.962	0	7.8E+09	7.8E+14
1.5E+03	2627.055	0	5.2E+09	5.2E+14
2.0E+03	1257.085	0	3.9E+09	3.9E+14
3.0E+03	468.45	1.05E-16	2.6E+09	2.6E+14
4.0E+03	215.833	4.35E-08	1.95E+09	1.95E+14
5.0E+03	117.2412	1.00E-04	1.56E+09	1.56E+14
6.0E+03	119.4314	8.44E-05	1.3E+09	1.3E+14
8.0E+03	164.5284	2.44E-06	9.75E+08	9.75E+13
1.0E+04	106.3914	0.000235	7.8E+08	7.8E+13
1.5E+04	37.96044	0.050721	5.48E+08	5.48E+13
2.0E+04	17.50937	0.252793	5.22E+08	5.22E+13
3.0E+04	5.923028	0.628014	6.99E+08	6.99E+13
4.0E+04	2.613364	0.814441	1.05E+09	1.05E+14
5.0E+04	1.369343	0.898033	1.53E+09	1.53E+14
6.0E+04	0.804036	0.938804	2.13E+09	2.13E+14
8.0E+04	0.348132	0.973028	3.62E+09	3.62E+14
1.0E+05	0.185283	0.985553	5.4E+09	5.4E+14
1.5E+05	0.067331	0.994726	9.86E+09	9.86E+14
2.0E+05	0.040174	0.99685	1.24E+10	1.24E+15

An example of calculation of characteristics of positioning for synchrotron radiation of APS ANL is presented in Appendix 1.

Operating principle

The principle of operating of Vibrating Wire Monitor is based on sensitivity of wire oscillations frequency to temperature. The novelty of the method is that the wire heating quantity is used as a source of information about the number of interacting particles/photons. The wire heating measurement is performed as a change of the wire natural oscillation frequency. The excitation of wire natural oscillations is provided by interaction of a current through the wire with a permanent magnetic field. A shift in the wire natural oscillation frequency characterizes the change in the conditions of wire irradiation by the measured beam. By the rigid fixing of the wire ends on the support an unprecedented sensitivity of the frequency to the temperature and to the corresponding flux of colliding particles is obtained.

Application

Vibrating Wire Monitor can be used for detecting both charged or uncharged particles and photons.

Technical details

Installation drawing

The main view of the VWM005 fixed on the flange of synchrotron radiation beam dump is presented at Fig. 5. VWM005 can be tilted at necessary angle.

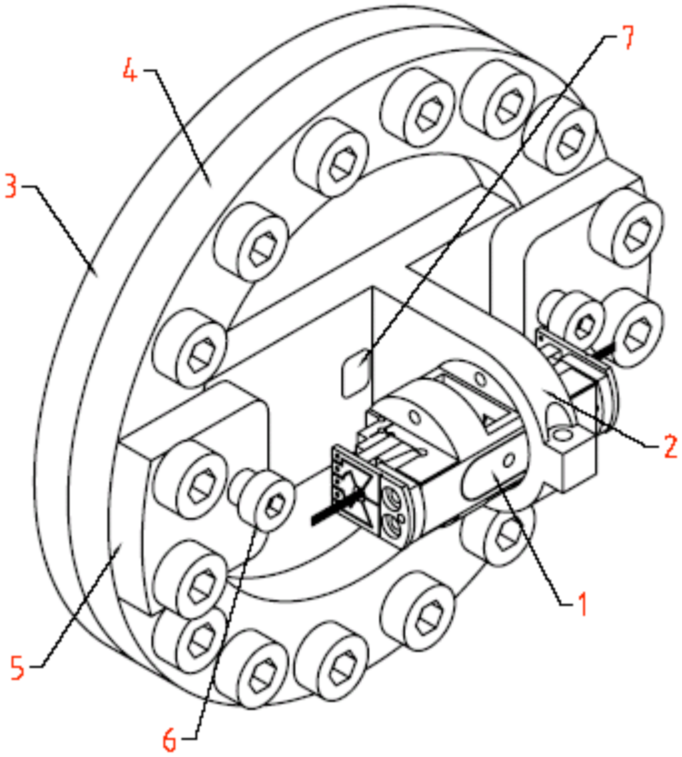

Fig. 5. Main view of VWM005 mounting on the flange. Parts: 1 – VWM005, 2 – VWM005 support, 3 – beam dump tube, 4 – beam dump flange, 5 – VWM005 mounting plates, 6 – clamp bolt, 7 – rectangular window for synchrotron beam accept with VWM005 aperture.

VWM support serve also as a screen to cut unwanted synchrotron radiation that heat VWM005 housing and un-exposed portion of the wires (see. Fig. 6). Synchrotron radiation passes through the rectangular window 5 accept the VWM005 working aperture. Holes 4 are provided for VWM005 support mounting on the flange (sizes must be defined).

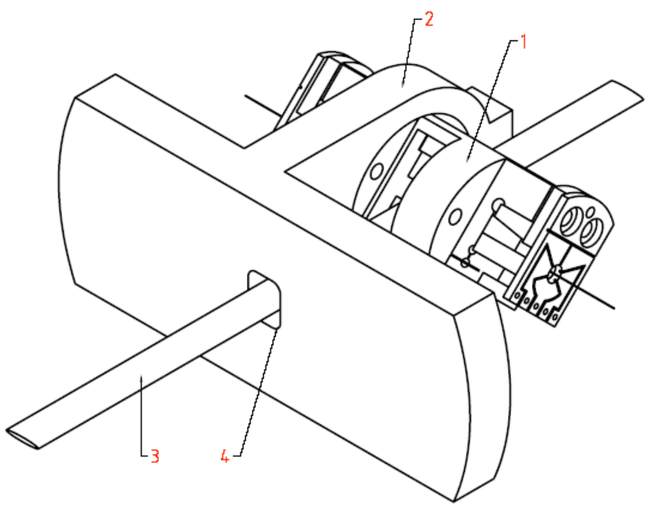

Fig. 6. View of the VWM005 support back side. Parts: 1 – VWM005 turned at 45^0 around central wire, 2 – VWM005 support, 3 – photon beam, 4 – rectangular window for synchrotron beam accept with VWM005 aperture.

At Fig. 7. some dimensions of the VWM005 are persented.

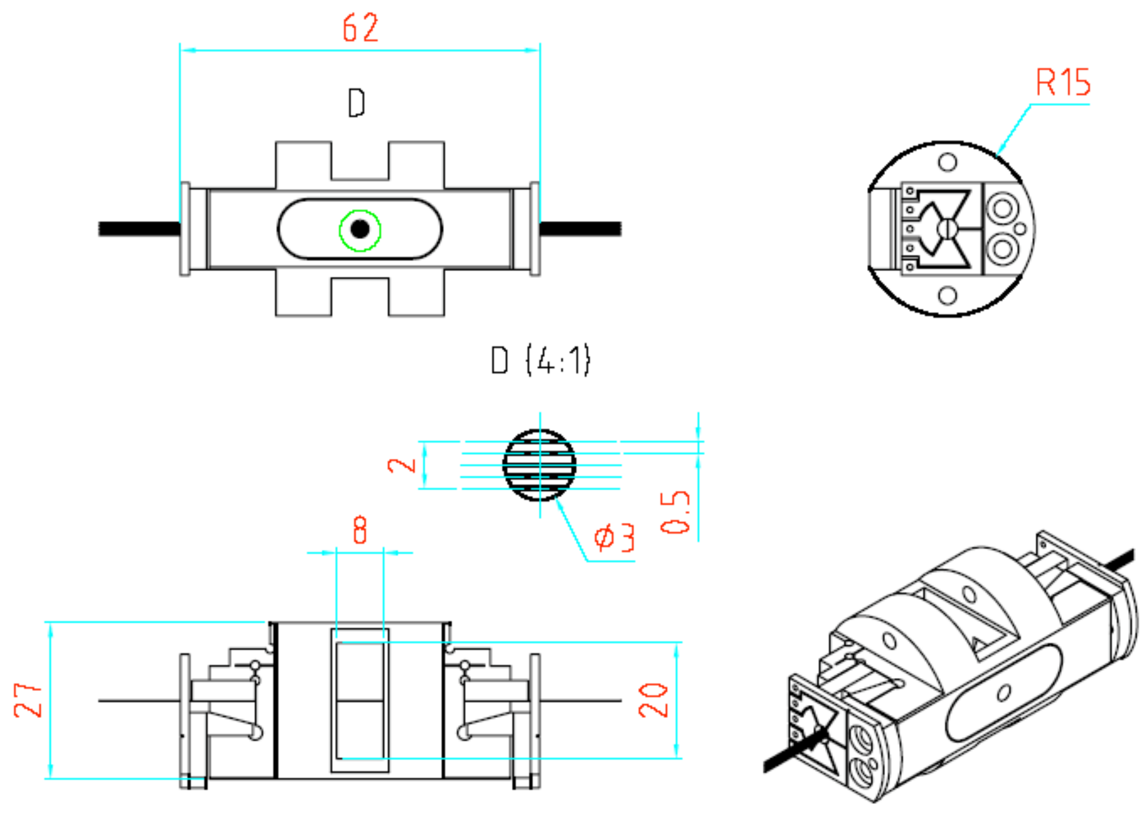

Fig. 7. Some dimensions of the VWM005.

The dimensions of the VWM005 support are presented at Fig. 8.

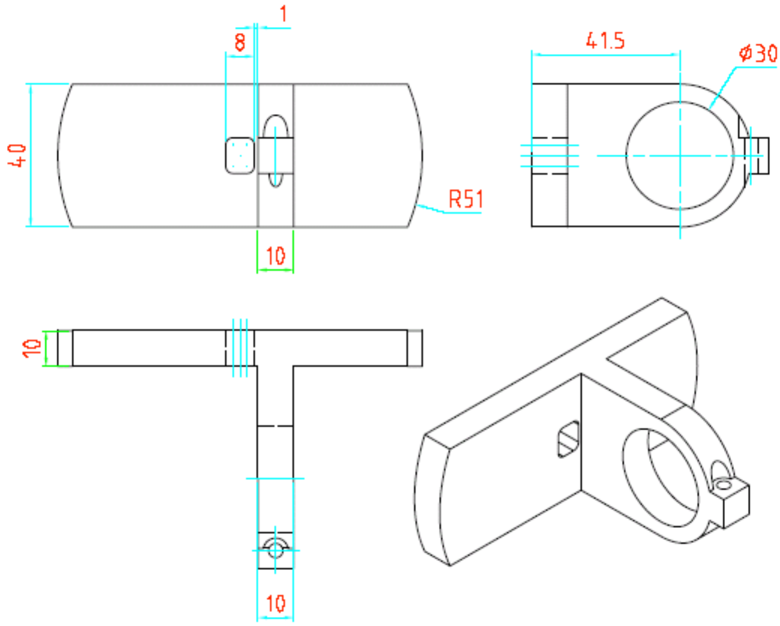

Fig. 8. VWM005 support optional dimensions.

Electronics, Data Format and Test Program

Connections and Protocol

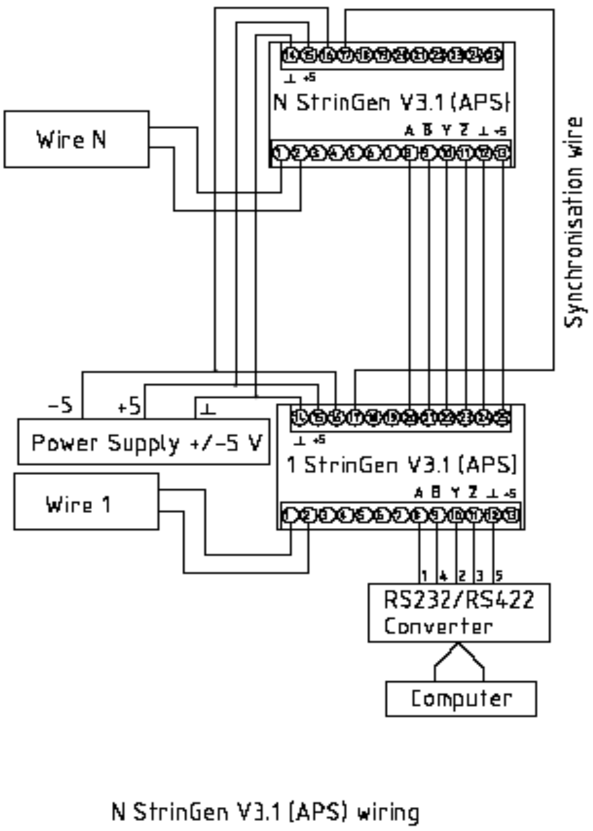

Fig. 9. Electronic unit inside wiring.

There are 5 *Stringen V3.1(APS)* plates inside the electronic unit (one for each vibrating wire). The plates measure the wires oscillation frequency and transfer in RS422 standard. If the

data will be transferred to the PC (e.g. if the test program *Stringener5* is used) RS232/RS422 converter is to be used.
The communication protocol is:

— BaudRate = 9600 bits/s
— Data bits = 8 bits
— Parity = No parity
— Stop bits = 1 stop bit

Scheme of connections inside the electronic unit is shown in Fig. 9.

Data Format

If the sensor is connected to the electronic unit after the electronic unit switch on the plates begin to transfer data. Sampling rate is 1000 ms. The data from different wires are transferred with about 150 ms shift. Number of bytes for each wire is 5: first byte is the plate number, bytes 2 to 5 are the corresponding wire frequency in kHz in Microchip 32-bit floating point format.

Byte No.	1	2	3	4	5
Description	Plate number	Frequency in kHz, Microchip 32-bit floating point format			
Bits	nnnn nnnn	eeee eeee	s.xxx xxxx	xxxx xxxx	xxxx xxxx

Plate numbers are 1 to 5 (hexidecimal 0x01 to 0x05) for electronic unit 1 and 6 to 10 for unit 2 (hexidecimal 0x06 to 0x0A). Byte 2 - 'eeeeeeee' - is the biased 8-bit exponent with bias = 127. In byte 2 's' is the sign bit (0 if positive and 1 if negative), '.' is the radix point. Bytes 3, 4 and 5 constitute the fraction with the most significant byte 3 with implicit most significant bit = 1. About Microchip FP32 format see, e.g. http://www.e-sonic.com/whatsnew/Microchip/control/AN575.pdf.

TEST PROGRAM STRINGENER5

Test program *Stringener5* reads frequencies from *Stringen* plates (if vibrating wire resonators are connected to plates), visualized them and saves in file.

Minimal system requirements

— IBM PC 300 MHz or higher
— Windows 98SE or higher
— 3MB on HDD for the program
— additional space for data files.

Installation

To install the program double click on the setup.exe and follow the setup program instructions. By default it is installed in folder *Program Files\Stringener5*. It can be changed at installation. In any case all data files will be saved in the same directory were the file Stringener.exe is.

Functioning

To start the program connect the PC serial port with electronic unit via RS232/422 convertor, set the correct serial port number and press the *Start* button. After start each second the data from all devices are obtained and visualized in two forms: numerical list boxes (one for each wire) and graphical. In graphical window the data are plotted on two axes. Drop-down lists above the graphical axes contain list of devices and data of selected devices are plotted on corresponding axis. Left and right axes can be separately zoomed in/out and moved up/down.

The data are saved in a file. To avoid large files not all data can be saved using the text box *Step*. Also the data can be averaged before the saving.

Appendix 1

1. Main expressions

Synchrotron radiation (SR) spectral angular (in horizontal plane) power distribution P:

$$\frac{d^2P}{d\alpha \cdot d(\varepsilon/\varepsilon_C)}[W/rad] = P_0[W]\frac{\rho[m]I[A]}{c[m/s]e[C]}\Upsilon(\varepsilon/\varepsilon_C), \qquad (1)$$

where α - is the angle in horizontal plane, ε - photon energy, $\varepsilon_C = 3\hbar c\gamma^2/2\rho$ - SR critical energy, γ - electrons Lorentz factor, ρ - electrons orbit radius, I - electron beam current.
Factor

$$P_0 = \frac{2r_0 mc^3\gamma^4}{3\rho^2} \qquad (2)$$

is instant total radiation power of an electron, $\hbar$ = 1.055E-34 J*s, c=3*10^8 m/s, e=1.6*10^{-19} C, r_0=2.82*10^{-15} m.
Normalized by unit spectral function $\Upsilon(y)$ is:

$$\Upsilon(y) = \frac{9\sqrt{3}}{8\pi}y\int_y^\infty K_{5/3}(x)\cdot dx, \qquad (3)$$

where $K_{5/3}$ - is the Bessel function ($\Upsilon(1)$=0.4040).

2. Beam dump, synchrotron radiation

APS parameters

Electron energy – 7 GeV, γ = 1.37*10^4
Bending magnet field – 0.599 T
Electrons orbit radius - 39 m
SR photon critical energy – 1.95*10^4 eV

Parameters of VWM005

Distance – 7 m
VWM horizontal aperture – 8 mm
VWM wire diameter - 0.1 mm
SR emitted in the horizontal angle corresponds to VWM005 aperture – 99.1 W (at I=100 mA)
The height of the SR beam at VWM position - 0.511 mm

For spectral power transfer through the material with thickness d and density ρ_d we use the expression:

$$\Upsilon(y)_{TRANSFER} = \Upsilon(y)_{INCIDNT} * \exp(-\frac{\mu(\varepsilon)}{\rho_d} * \rho_d * d) \quad ,$$

where $\mu(\varepsilon)/\rho_d$ - mass attenuation coefficient.

For spectral power deposited into the vibrating wire we use expression

$$\mathrm{Y}(y)_{DEPOSTED} = \mathrm{Y}(y)_{INCIDNT} * (1 - \exp(-\frac{\mu_{EN}(\varepsilon)}{\rho_d} * \rho_d * d)),$$

where $\mu_{EN}(\varepsilon)/\rho_d$ - mass energy-absorption coefficient.

Used spectral parameters for synchrotron radiation beam attenuation in 6 mm Cu and deposited into the wire are [NIST]:

ε, eV	μ/ρ Cu, cm²/g	μ/ρ Wire, cm²/g	Y(y)	Y_{Cu}(y)	Y_{Wire}(y)
1.00E+03	1.06E+04	8.70E+03	4.04E-01	0.00E+00	0.00E+00
1.50E+03	4.42E+03	3.30E+03	4.04E-01	0.00E+00	0.00E+00
2.00E+03	2.15E+03	1.58E+03	4.04E-01	0.00E+00	0.00E+00
3.00E+03	7.49E+02	5.89E+02	4.04E-01	0.00E+00	0.00E+00
4.00E+03	3.47E+02	2.71E+02	4.04E-01	0.00E+00	0.00E+00
5.00E+03	1.90E+02	1.47E+02	4.04E-01	0.00E+00	0.00E+00
6.00E+03	1.16E+02	1.50E+02	4.04E-01	0.00E+00	0.00E+00
8.00E+03	5.26E+01	2.07E+02	4.04E-01	0.00E+00	0.00E+00
1.00E+04	2.16E+02	1.34E+02	4.04E-01	0.00E+00	0.00E+00
1.50E+04	7.41E+01	4.77E+01	4.04E-01	0.00E+00	0.00E+00
1.95E+04	3.38E+01	2.20E+01	4.04E-01	0.00E+00	0.00E+00
3.00E+04	1.09E+01	7.44E+00	3.10E-01	0.00E+00	0.00E+00
4.00E+04	4.86E+00	3.28E+00	1.96E-01	9.54E-13	3.46E-14
5.00E+04	2.61E+00	1.72E+00	1.24E-01	1.03E-07	2.06E-09
6.00E+04	1.59E+00	1.01E+00	7.85E-02	1.54E-05	1.85E-07
8.00E+04	7.63E-01	4.37E-01	3.09E-02	5.18E-04	2.73E-06
1.00E+05	4.58E-01	2.33E-01	1.20E-02	1.03E-03	2.91E-06
1.50E+05	2.22E-01	8.46E-02	1.08E-03	3.30E-04	3.40E-07
2.00E+05	1.56E-01	5.05E-02	9.40E-05	4.08E-05	2.51E-08
3.00E+05	1.12E-01	3.43E-02	6.66E-07	3.66E-07	1.53E-10
4.00E+05	9.41E-02	3.07E-02	4.51E-09	2.72E-09	1.02E-12
5.00E+05	8.36E-02	2.93E-02	2.97E-11	1.89E-11	6.79E-15

With $\int Y(y)dy = 1$, $\int Y_{Cu}(y)dy = 4.24e-3$, $\int Y_{Wire}(y)dy = 1.14e-5$.

The whole SR power P_0 emitted into the VWM aperture horizontal angle is 99.1 W (at electron beam current 100 mA). Power attenuation after 6 mm copper is 420 mW, while dissipated power is 1.13 mW. Corresponding graphics are presented in Fig. 1.

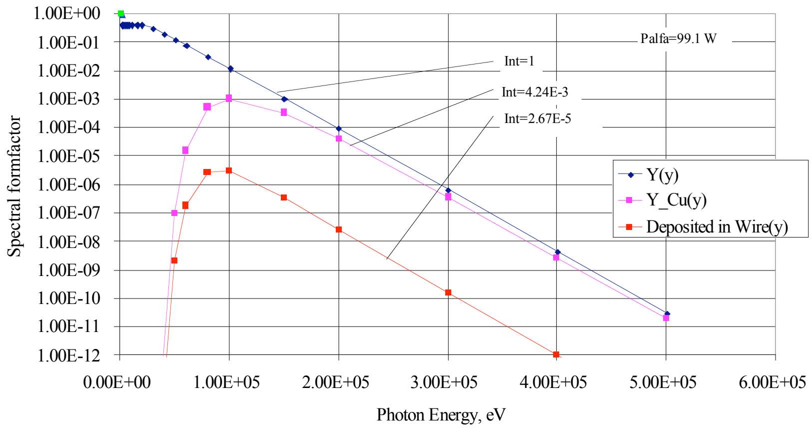

Fig. 1. Power attenuation of 99.1 W synchrotron radiation after 6 mm copper is 420 mW, and power dissipated into the wire is 1.13 mW.

Vertical positioning

The power converted to the wire overheating at its shift to the height z is

$$P_{Wire} = P_0 * \int Y_{Dep}(y)dy * \frac{d}{\sqrt{2\pi}\sigma_Z} \exp(-z^2 / 2\sigma_Z^2)$$

The accuracy of positioning of the wire equals $\Delta P_{Wire} / (dP_{Wire} / dz)$, where ΔP_{Wire} is the accuracy of the pickup depending on the power absorbed by the wire. For mentioned example in hour interval measurements the accuracy of positioning depending on z at $\sigma_Z = 0.5$ mm is presented in Fig. 2. The minimal value 9 μm is obtained at $z \approx \sigma_Z$.

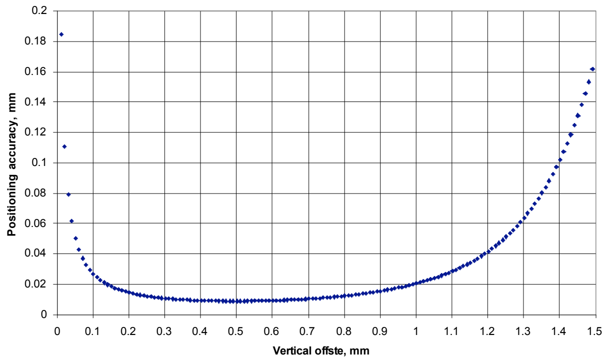

Fig. 2. Positioning accuracy.

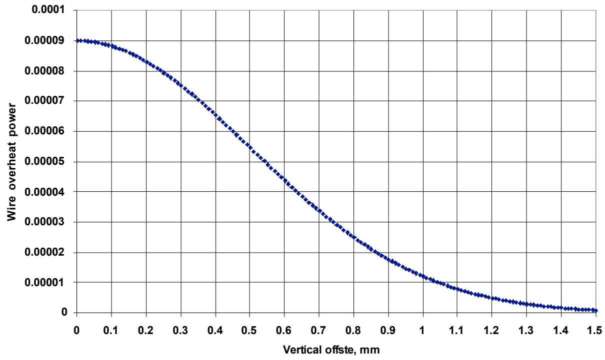

Fig. 3. Wire overheating depending on wire position.