VIBRATING WIRE MONITORS FOR BEAM AND IONIZATION RADIATION INSTRUMENTATION

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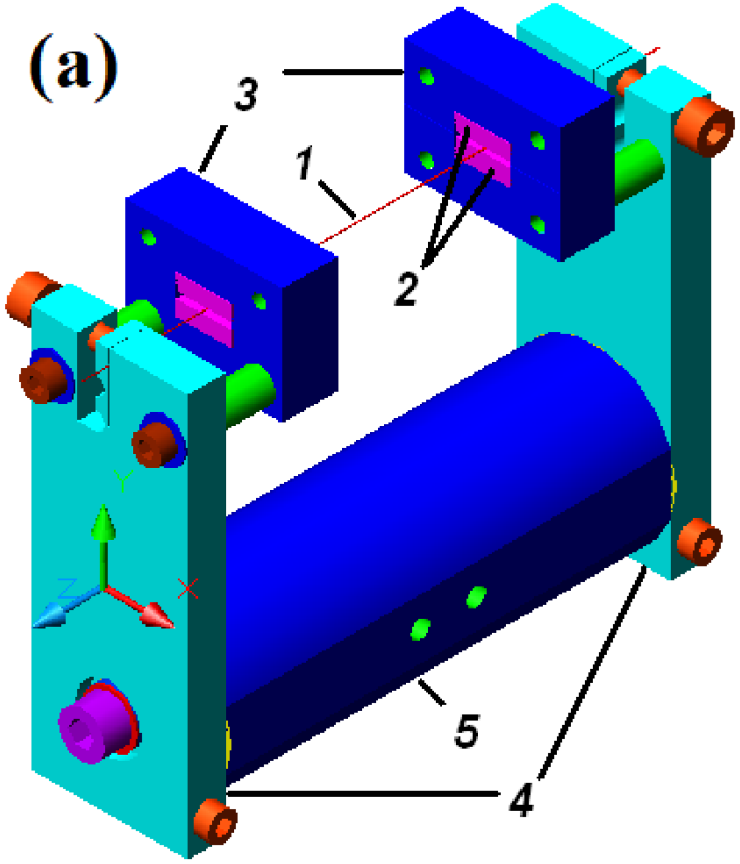
Outline:

Vibrating Wire Resonator
VWM as thermometer
Scanner for beam profiling

VWM as resonant target
VWM as miniature scanner
VWM for monitoring of structural changes in wire material under long-term radiation exposure

Typical Vibrating Wire Resonator

S.G. Arutunian et al., Vibrating wire monitor: Versatile instrumentation for particle and photon beam measurements with wide dynamic range, JINST, 2021, 16, R01001, 1-33.



A typical vibrating wire monitor with a single wire and a two-component magnetic system along the wire, freeing the central part of the wire for interaction with the measured object.

1 — vibrating wire
2 — magnets
3 — magnet poles
4 — clamps
5 — basis/supporting part

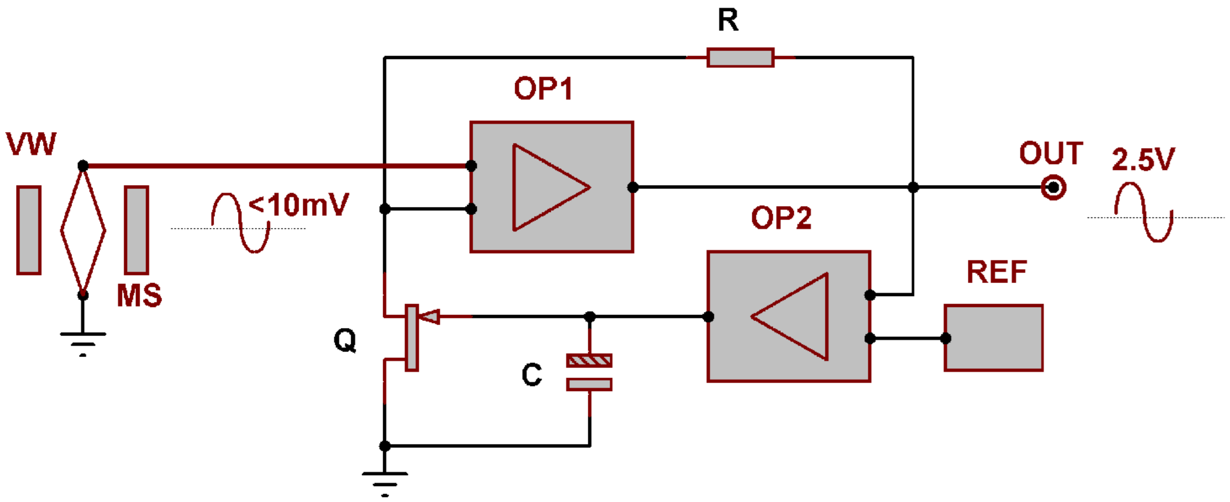
The operating principle of diverse vibrating wire sensors is based on the measurement of a change in the frequency of the vibrating wire that is stretched on a support, as a function of the physical parameters of the wire and the environment in which the oscillations occur.

There are numerous different types of vibration wire sensors (geotechnical and structural engineering to measure strain, pressure, load, and displacement, temperature measurements etc)

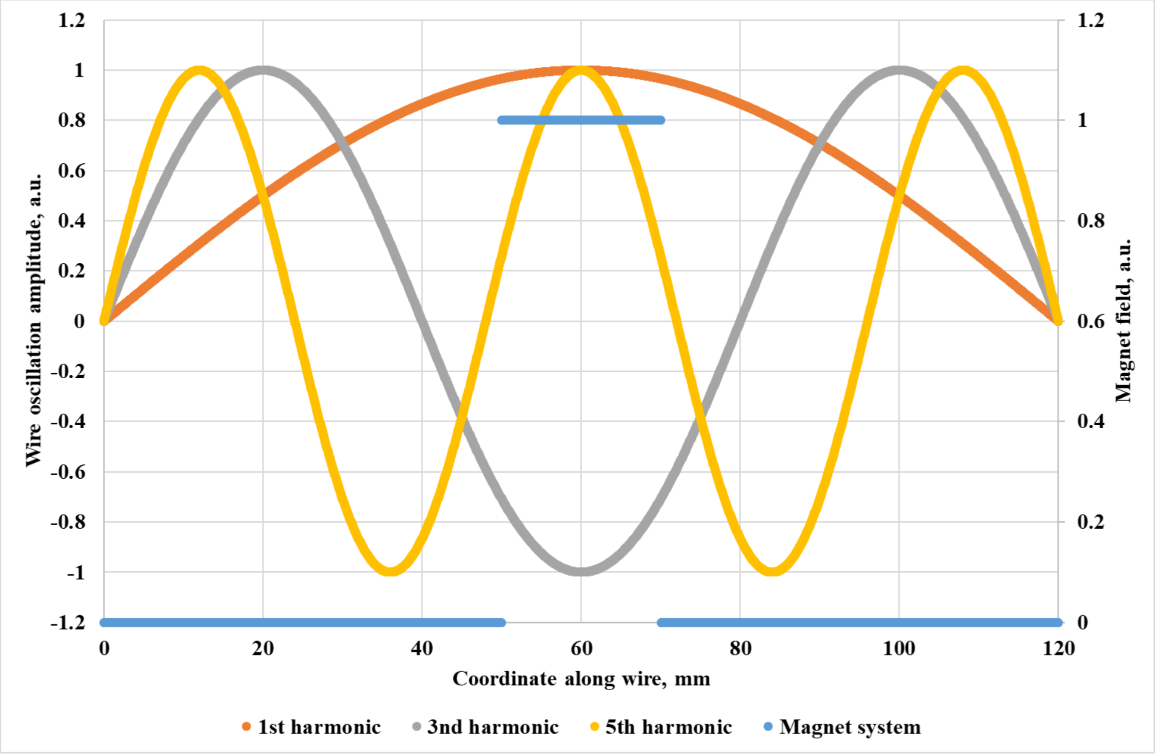
- In the permanent excitation method, an electrical energy impulse maintains sufficient energy in the wire for its permanent oscillation.

- In the resonance method, typically two electromagnets are used. The first one acts as an actuator, whereas the second one serves as a sensor for the oscillation frequency observation.

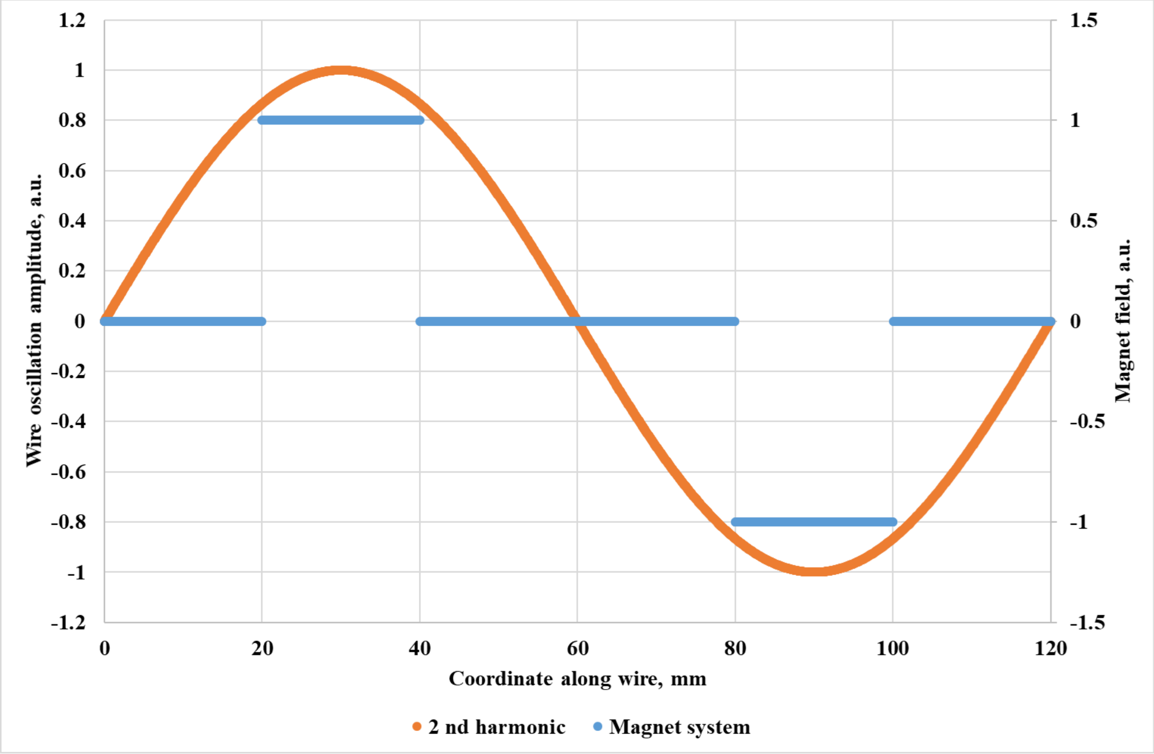
- In the impulse method, an electromagnet serves as a shock actuator as well as a velocity sensor. An electrical impulse through an electromagnetic coil applies a very brief point force on the wire. After some time, the first mode component of the free response dominates.



Board of automatic generation of natural oscillations of the wire (schematically)
VW — vibrating wire, MS — magnetic system
OP1 — main operational amplifier
OP2 — operational amplifier for wire oscillation amplitude stabilization
REF — voltage reference source that regulates oscillation amplitude
Q — field transistor in circuit of wire vibration amplitude stabilization
R — resistor (nominal is selected depending on parameters of resonator)
C — capacitor that adjusts process of signal stabilization
OUT — output signal



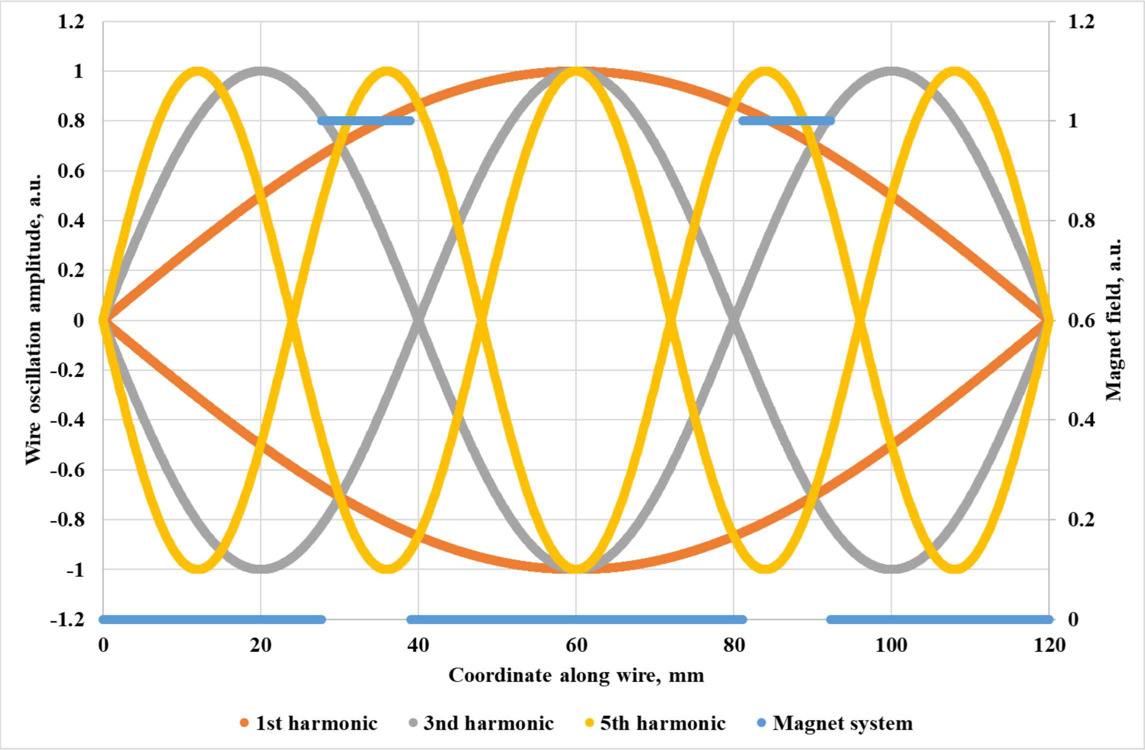
Odd harmonics



Even harmonic

A spatially localised magnetic field can create uncertainty in the generation of a selected harmonic

Well adjusted field configuration

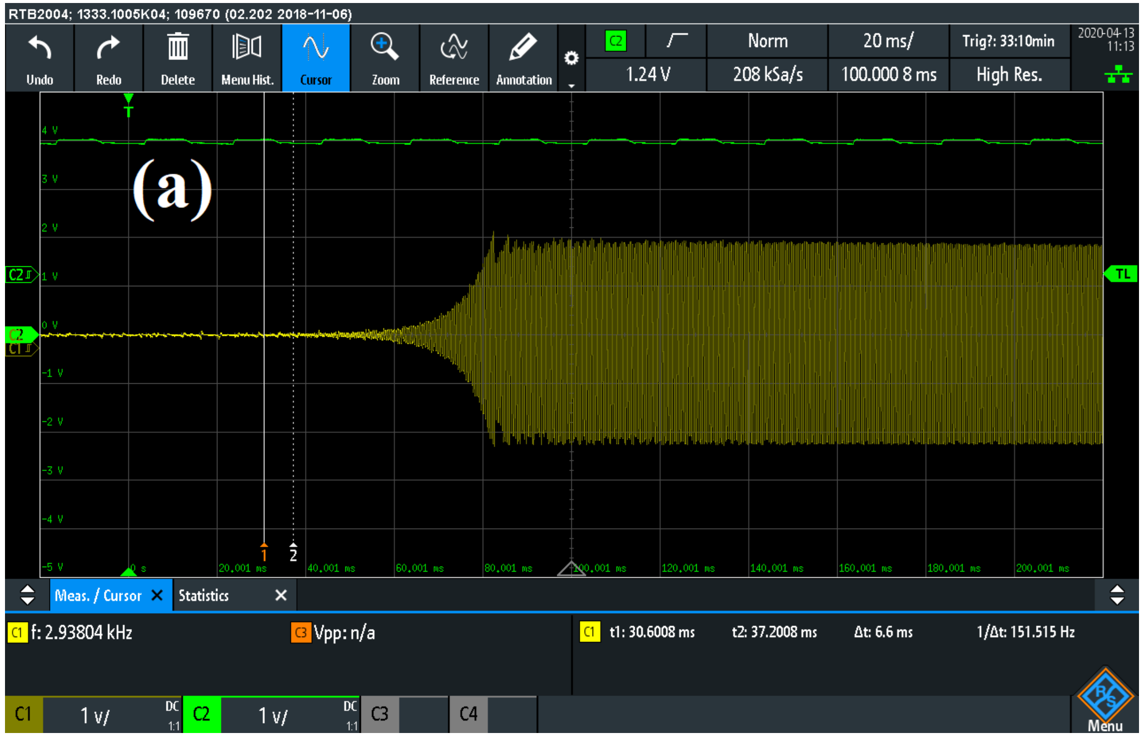


The process of exciting oscillations is quite complex and time-consuming. It depends on the parameters of the excitation circuit, the geometry and magnitude of the magnetic field, the material and quality of the wire, the method of fastening the ends of the wire, atmosphere/vacuum.

It is obvious that the magnetic field gap must be clean and free of magnetized particles.

Generation of odd harmonics can also be obtained for a decentralized magnetic field. However, this may generate the first, third, and fifth harmonics.

Autogeneration process using 120-mm wire length monitor, autogeneration board StrGen StrGEN_DVW_FREQ with operational amplifier LM833 in SMD version, and capacitor C = 3300 nF

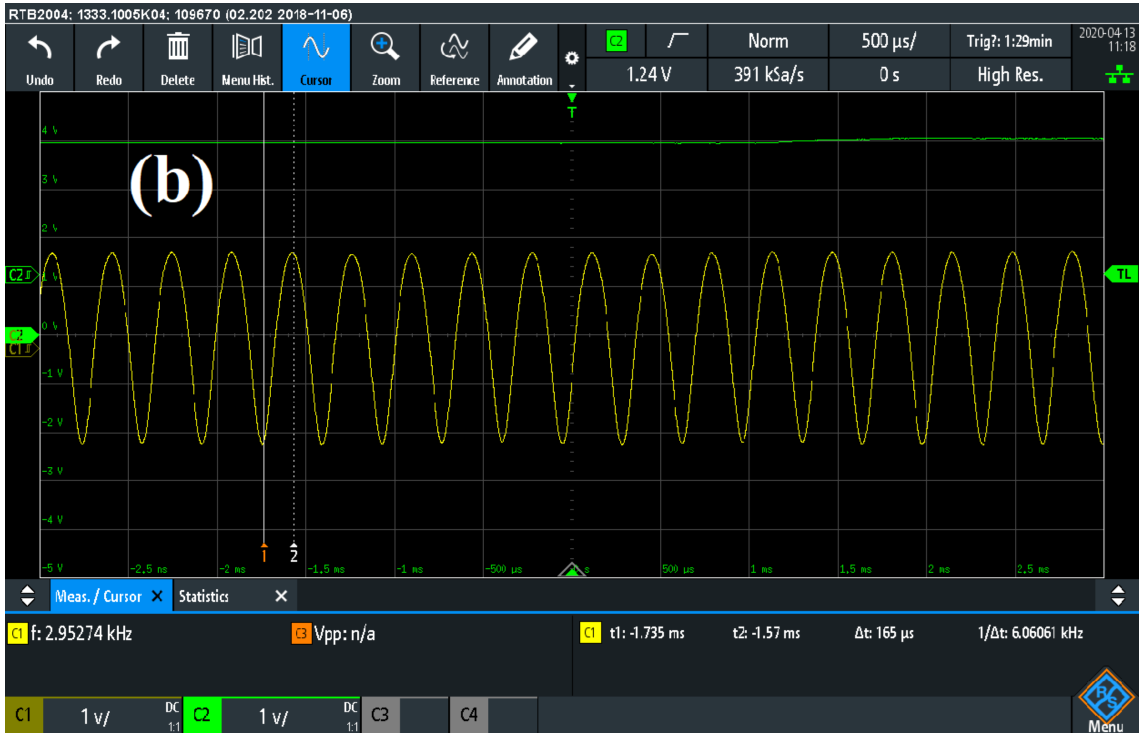


Norm | 20 ms/ | Trig?: 33:10min | 1.24 V | 208 kSa/s | 100.000 8 ms | High Res.

f: 2.93804 kHz | Vpp: n/a | t1: 30.6008 ms | t2: 37.2008 ms | Δt: 6.6 ms | 1/Δt: 151.515 Hz

C1 1 V/ DC 1:1 | C2 1 V/ DC 1:1

(a) Because of high capacitor values in feedback circuit, autogeneration process starts after approximately 3 s, and the fifth harmonic is generated. Horizontal scale of the oscilloscope waveform is 20 ms per division



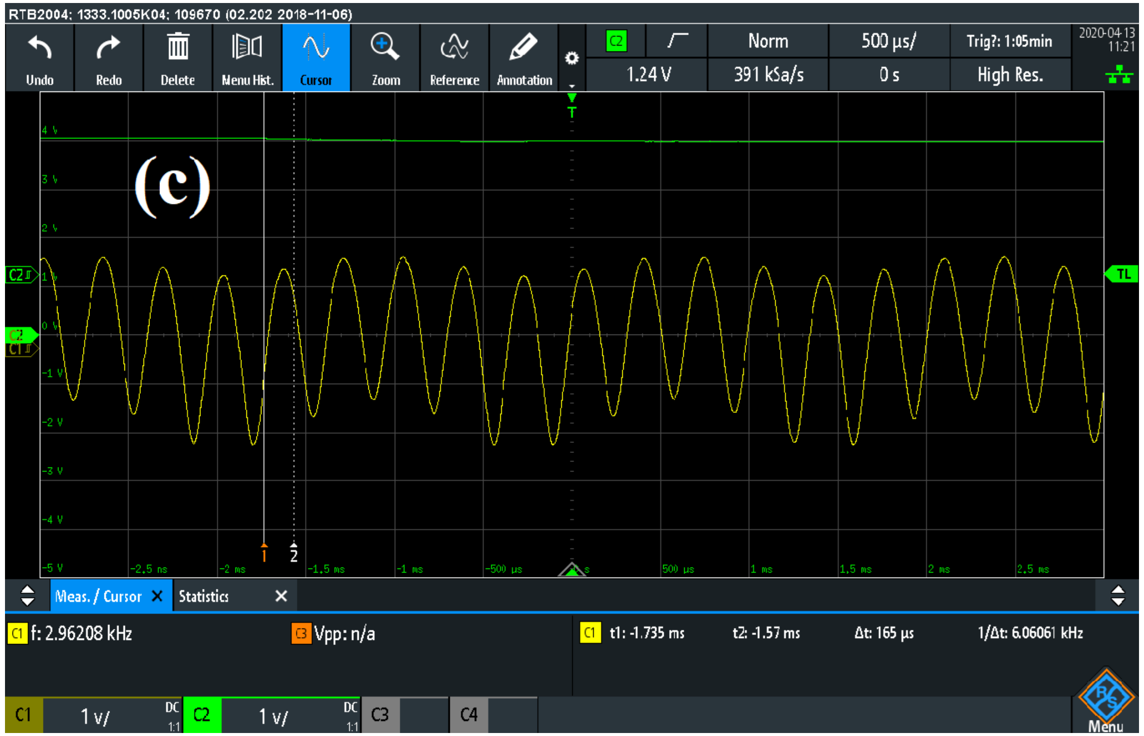
Norm | 500 µs/ | Trig?: 1:29min | 1.24 V | 391 kSa/s | 0 s | High Res.

f: 2.95274 kHz | Vpp: n/a | t1: -1.735 ms | t2: -1.57 ms | Δt: 165 µs | 1/Δt: 6.06061 kHz

C1 1 V/ DC 1:1 | C2 1 V/ DC 1:1

(b) Fifth harmonic sustains for sufficiently long time (up to 5 s). Horizontal scale of the oscilloscope waveform is 500 µs per division.

… similar process of oscillation generation of the same resonator with an StrGen V4.1USB board, which used operating amplifier in the DIP version and capacitor C = 220 nF

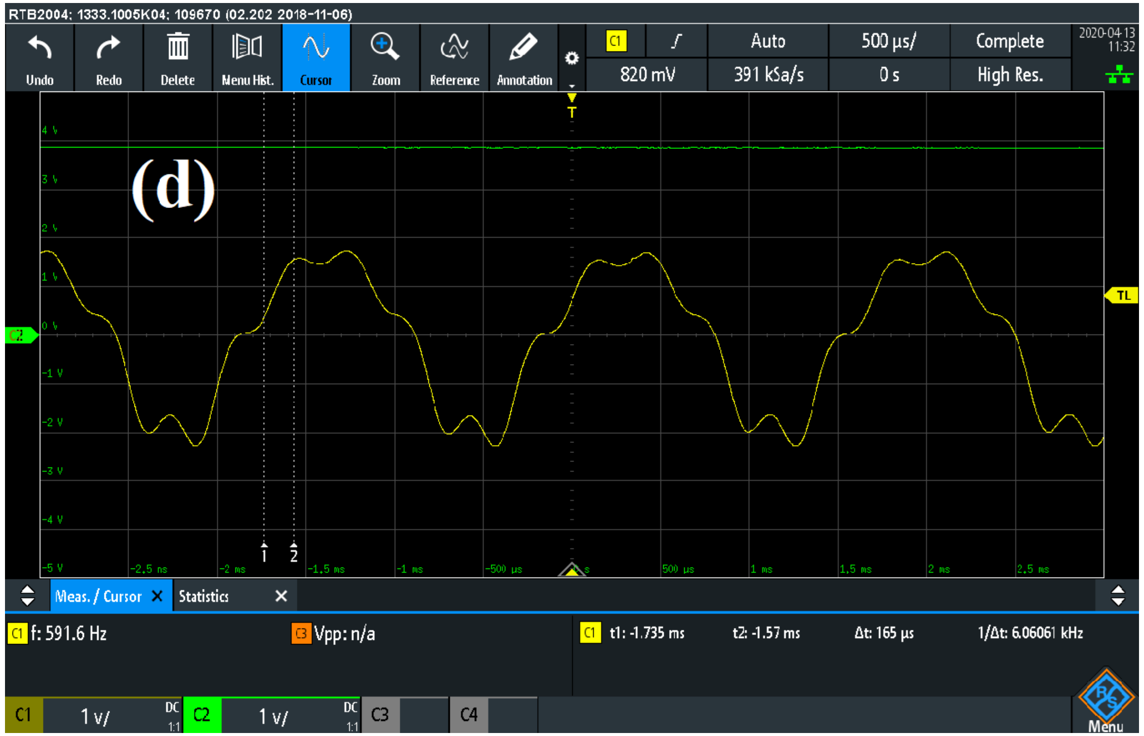


C1 f: 2.96208 kHz

C3 Vpp: n/a

C1 t1: -1.735 ms t2: -1.57 ms Δt: 165 µs 1/Δt: 6.06061 kHz

(c) Subsequently, together with the fifth harmonic, first harmonic (12 s) increases. Horizontal scale of the oscilloscope waveform is 500 µs per division.

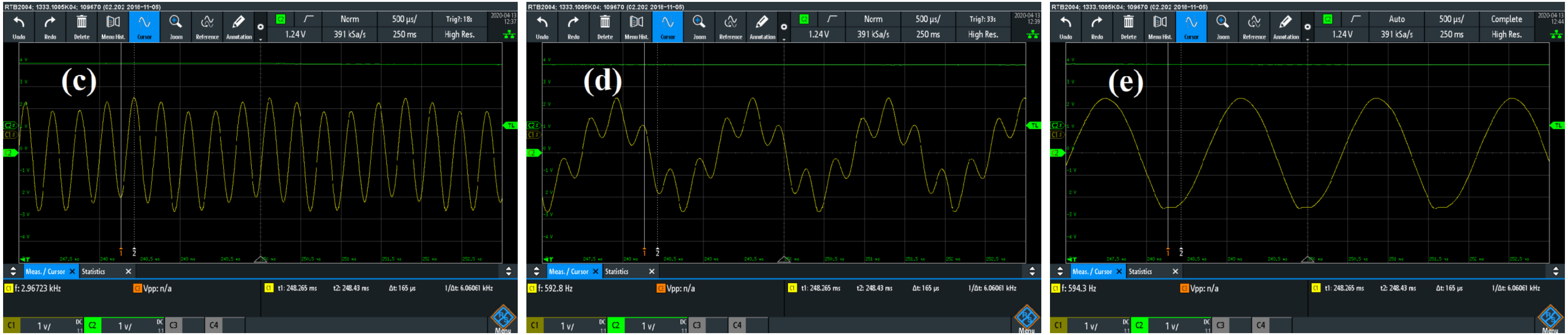


C1 f: 591.6 Hz

C3 Vpp: n/a

C1 t1: -1.735 ms t2: -1.57 ms Δt: 165 µs 1/Δt: 6.06061 kHz

(d) System enters stationary mode (over 30 s), with a mixture of first and fifth harmonics, in which fifth harmonic is important. Horizontal scale of the oscilloscope waveform is 500 µs per division.



RTB2004; 1333.1005K04; 109670 (02.202 2018-11-06)

(c) Norm 500 µs/ Trig?: 18s 2020-04-13 12:37 1.24 V 391 kSa/s 250 ms High Res.
C1 f: 2.96723 kHz C3 Vpp: n/a C1 t1: 248.265 ms t2: 248.43 ms Δt: 165 µs 1/Δt: 6.06061 kHz
C1 1 V/ DC C2 1 V/ DC

(d) Norm 500 µs/ Trig?: 33s 2020-04-13 12:39 1.24 V 391 kSa/s 250 ms High Res.
C1 f: 592.8 Hz C3 Vpp: n/a C1 t1: 248.265 ms t2: 248.43 ms Δt: 165 µs 1/Δt: 6.06061 kHz
C1 1 V/ DC C2 1 V/ DC

(e) Auto 500 µs/ Complete 2020-04-13 12:44 1.24 V 391 kSa/s 250 ms High Res.
C1 f: 594.3 Hz C3 Vpp: n/a C1 t1: 248.265 ms t2: 248.43 ms Δt: 165 µs 1/Δt: 6.06061 kHz
C1 1 V/ DC C2 1 V/ DC

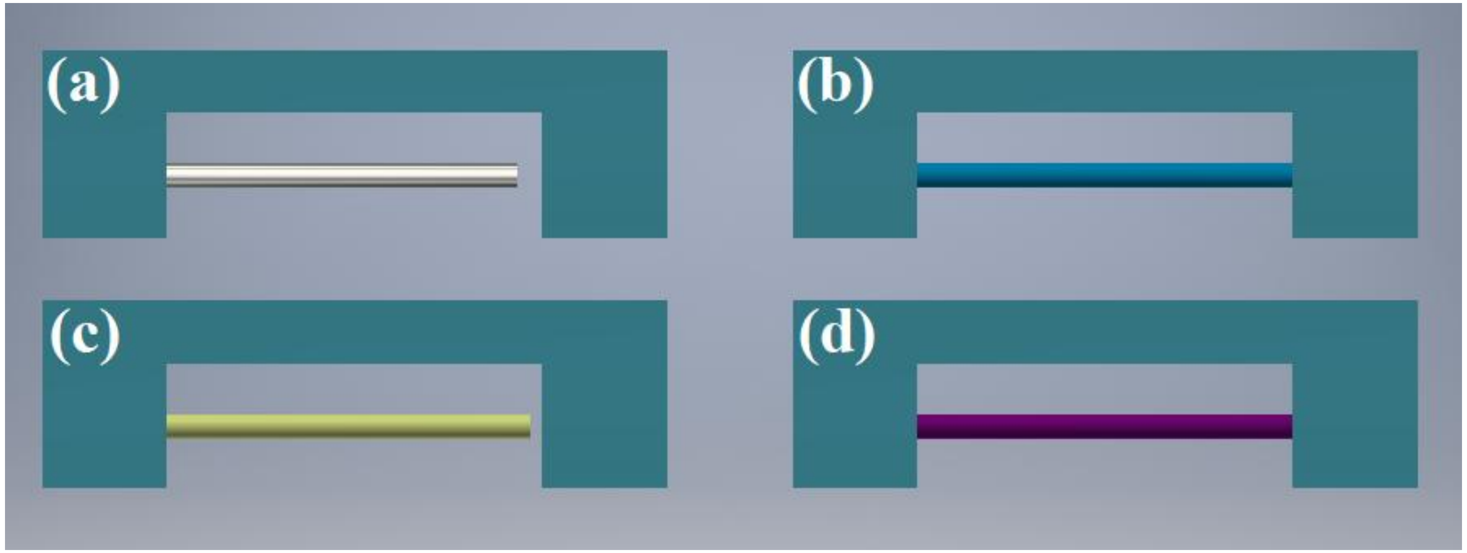
The transition from the fifth harmonic to the first can sometimes take several seconds

The images above refer to a case where the wire is long (120 mm) and the magnetic field sections have a short spatial extent along the wire. The vibrating wire resonators we use in practice have a length of 30 to 60 mm, and the magnetic field is located at about half the length of the wire. The most reliable generation is obtained for the variant with two magnetic field sections with opposite polarity, when the second harmonic is excited. The central part of the field is used for measurement.

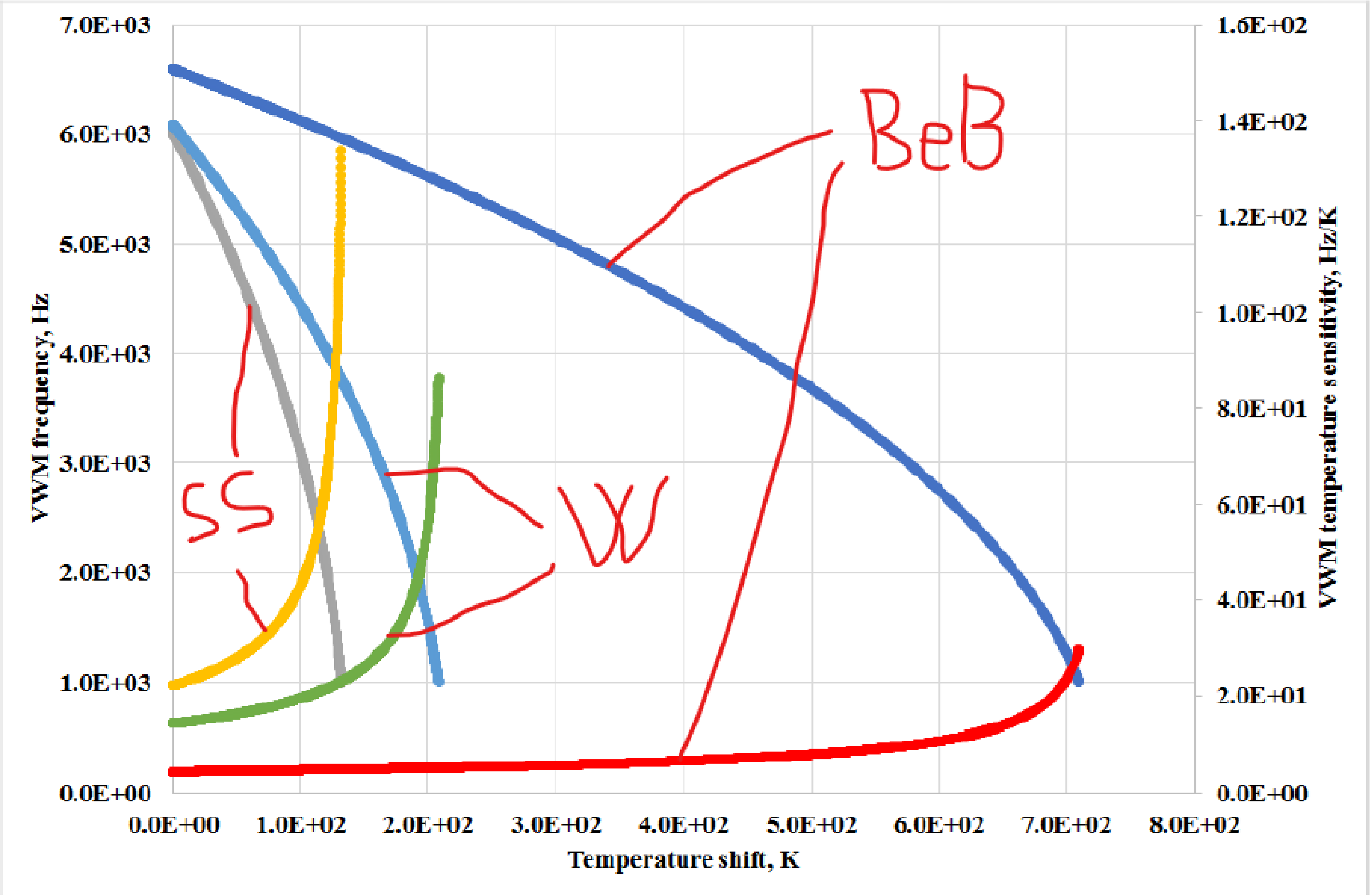
VWM as thermometer, here wire is thermometer

$$F = \frac{1}{L}\sqrt{(\sigma_o - E_W \alpha_W \Delta T)/\rho}.$$

L	Wire length
σ_0	Initial tension of the wire
α_W	Wire linear expansion coefficient
E_W	Wire elasticity modulus
ρ	Wire density,
ΔT	Wire temperature change



Tensioning wire when only its temperature changes.
(a) Base (cadet blue) — length of bed for wire = 30 mm, length in non-tensioned wire = 28 mm.
(b) Wire (sky blue medium) is stretched on bed length of base and becomes = 30 mm, i.e., tension of wire is calculated using wire elongation = 2 mm.
(c) For base, temperature does not change, i.e., bed length remains 30 mm, whereas on heating, length of non-tensioned wire (satin lemon chiffon) increases to 29 mm.
(d) Wire (smooth purple) is stretched along bed length of base and becomes 30-mm long, i.e., wire tension is calculated using wire elongation = 1 mm.



Frequency of vibrating wire and sensitivity of monitor to overheating of wire as functions of temperature of wire with wires formed of tungsten, beryllium bronze, and stainless steel. Sensitivity of monitor is slope of frequency versus temperature relation. In all three cases, it is assumed that during assembly, wire is stretched by 70% of the strength of material.

+++ Frequency dependence on ambient temperature

VWM is affected by the ambient temperature and wire is also exposed to a local heat source:

$T_A(t)$ — ambient temperature,

$T_B(t)$ — temperature of the VWM base,

$T_W(t)$ — temperature of the VWM wire.

We assume that the ambient temperature variation is sufficiently gradual

$$T_A(t) = T_B(t).$$

Temperature of the wire is divided into two components:
the ambient temperature and the excess over this temperature due to the local source that only affects the wire.

$$T_W(t) = T_A(t) + T^{\mathrm{ag}}(t).$$

At the start of the experiment $T_A(0) = T_B(0) = T_W(0) = T_0,$

$$F(t) = \frac{1}{L}\sqrt{(\sigma_o + E_W(\alpha_B - \alpha_W)(T_A(t) - T_0) - E_W \alpha_W T^{\mathrm{ag}}(t))/\rho}.$$

Thermal balance of VWM

The wire temperature increase relative to initial temperature can be calculated by the equation of balance between the power deposited in the wire and the heat sink through all possible thermal mechanisms. These mechanisms are
conduction along the wire to the end clips,
convection losses to the ambient atmosphere (if air or another gas is present),
losses through the radiation to the ambient space.

$$W_{\mathrm{beam}} = W_{\lambda} + W_{\mathrm{rad}} + W_{\mathrm{conv}},$$

$$W_{\lambda} = 8\,(T - T_0)\,\lambda S/L$$

$$W_{\mathrm{rad}} = \varepsilon\sigma_{ST\_B} T_W^4 \pi d L - \varepsilon\sigma_{ST\_B} T_0^4 \pi d L$$

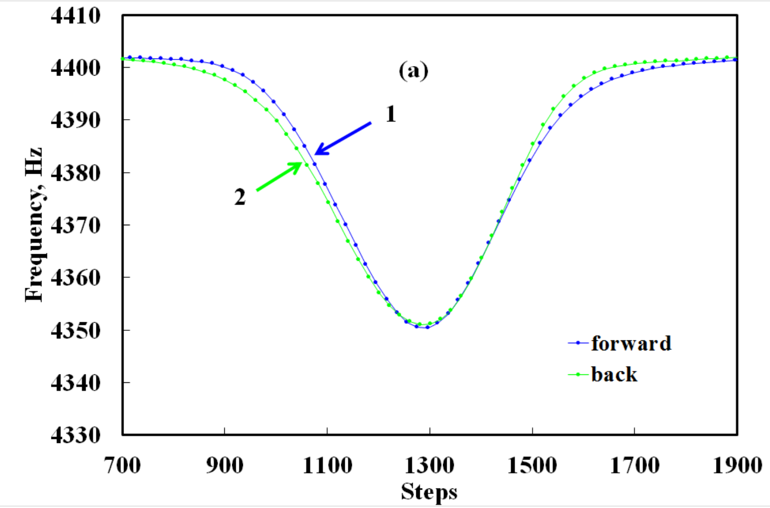
$$W_{\mathrm{conv}} = \delta\,(T_W - T_0)\,\alpha_{\mathrm{conv}} \pi d L$$

$$\Delta T = (T_{\mathrm{W,MEAN}} - T_0)/2$$

$$\Delta T = \frac{W_{\mathrm{beam}}}{8\lambda S/L + 4\varepsilon\sigma_{ST\_B} T_0^3 \pi d L + \delta\alpha_{\mathrm{conv}} \pi d L}.$$

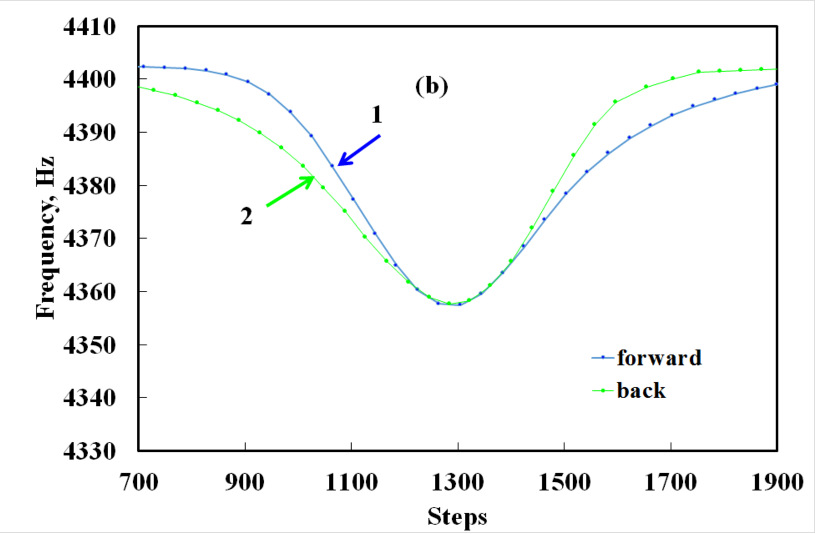
	Frequency resolution, Hz	Thermal resolution, mK	Deposited power resolution (vacuum), uW	Deposited power resolution (air), uW	Response time (vacuum), s	Response time (air), s	Dynamic range
Stainless steel	0.01	0.3	0.007	1	20	0.23	7.1×10^{5}
Bronze	0.01	0.6	0.05	2.6	9	0.21	3.5×10^{5}
Tungsten	0.01	1	0.3	5.4	2	0.16	4.4×10^{5}

Thermal inertia of a wire imposes certain restrictions on the scanning process at different speed



V_scan about 0.08 mm/s

1 mm = 600 steps



V_scan about 0.33 mm/s

A mathematical framework for two-parameter correction based on forward and backward scanning is currently being developed

- a time constant parameter is introduced
- a delay equation due to thermal inertia- offset between forward and backward scanning profiles

More about electronics

Based on our accumulated experience, we have concluded that the optimal electronic circuit is as follows

Autogenerator located in close proximity to the beam (front-end electronics) with a sinusoidal output signal. Power is supplied from the read-out board placed in control room

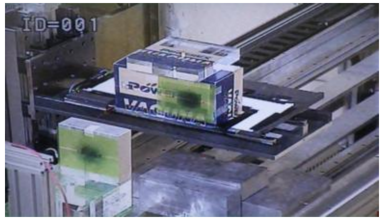
The signal is then transmitted via a shielded LAN cable. One cable is sufficient to operate two VWM, including the power supply. Cables 50 m in length were typically used, although tests were conducted with a 200 m cable. Power is supplied at 12 V and subsequently converted to ±5 V. A 12 V voltage drop does not pose a problem. The output frequency amplitude of the front-end electronics is approximately 2.5 V amplitude. Experience has shown that special line drivers (like DRV135) are not necessary.

Initially, low-pass filters were installed on the input of read-out board; however, experience showed that they were not necessary under the conditions we were working with. If needed, such filters can be installed. At the read-out input, the sinusoidal signal was amplified to 5 V and converted by a comparator into a square-wave signal, which was fed to the digital input of the microcontroller (in the first versions, PIC18F256; in later versions, Attiny2313). The interface with the PC was implemented using a USB-COM converter. A separate microcontroller was used for each frequency channel.

Formally speaking, the task of moving the sensor using a stepper motor is not actually a problem for our methodology. However, we often had to address this issue as well, since reliable positioning systems are quite expensive and require coordination with the readout board. We, on the other hand, developed an application for collecting and visualizing data.

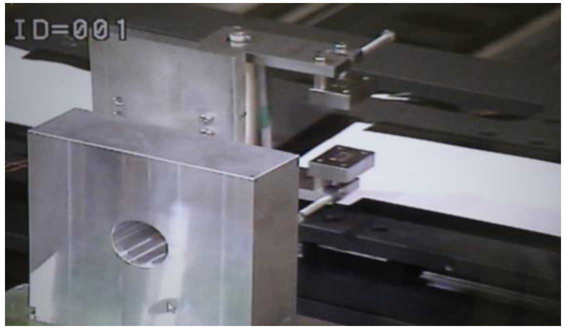
VWM Experiment Conditions at KOMAC, 2016

Energy of proton beam: 20 MeV at exit from vacuum chamber, 14.5 at VWM position (1 m from exit) in air
Repetition rate: 1 Hz, Mean current: 100 nA (at 1 Hz rep. rate)



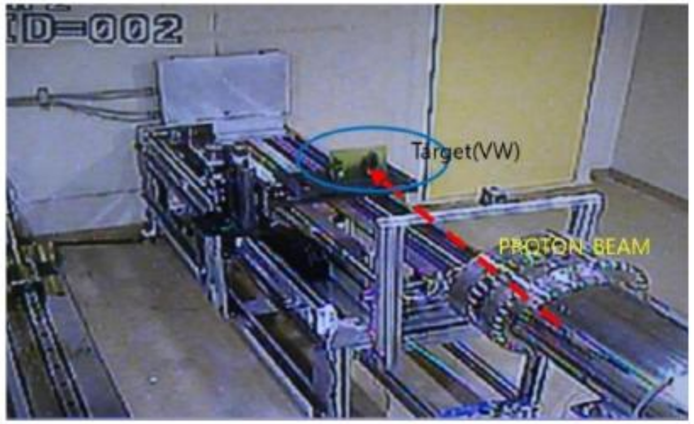
Collimator and convection protection box, covered with film CAFCHROMIC

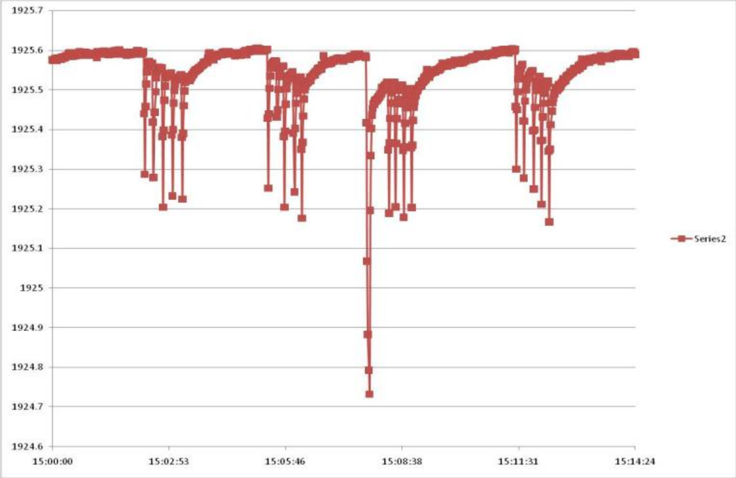
VWM mounted on the 3D table



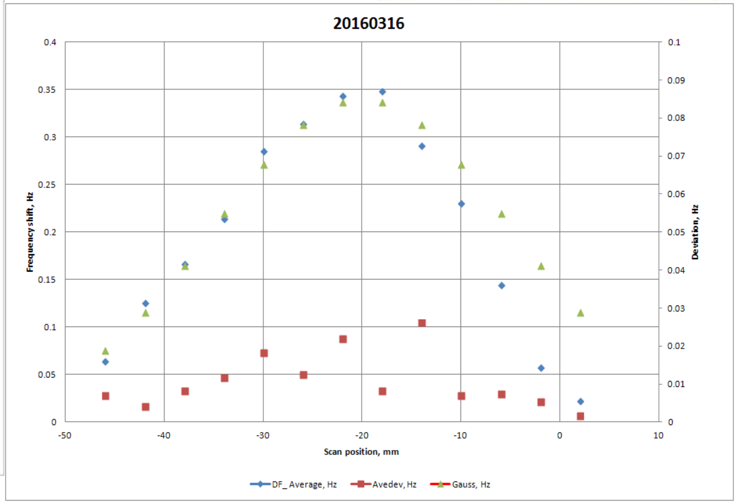
30 mm collimator, VWM aperture 40 mm

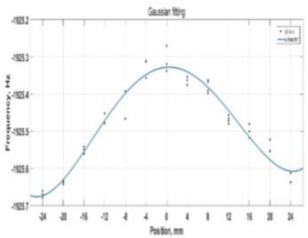
(VWM) has been installed and tested at TR23 target room





one train - 10 sec pause



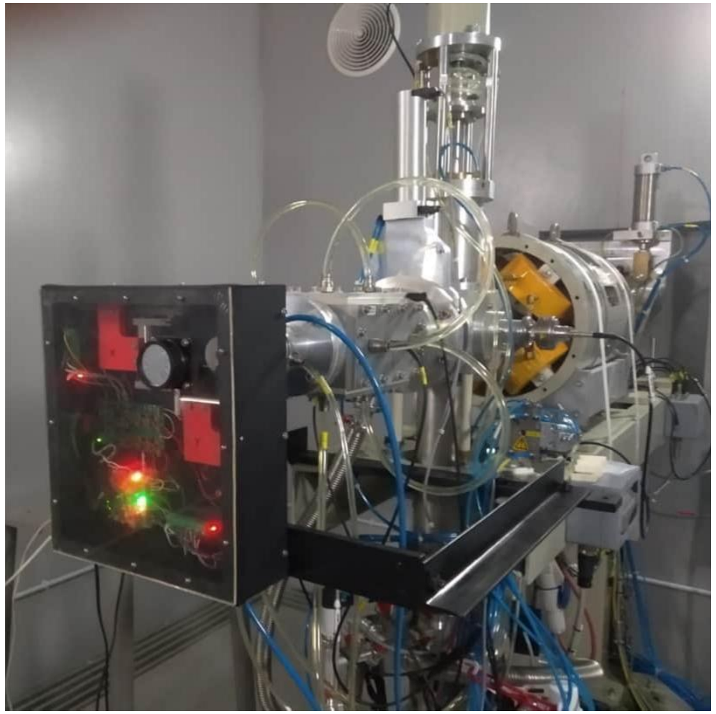


Blue dots - reconstruction
Green dots - Gaussian with sigma 15 mm
Red dots – deviation (right axis)

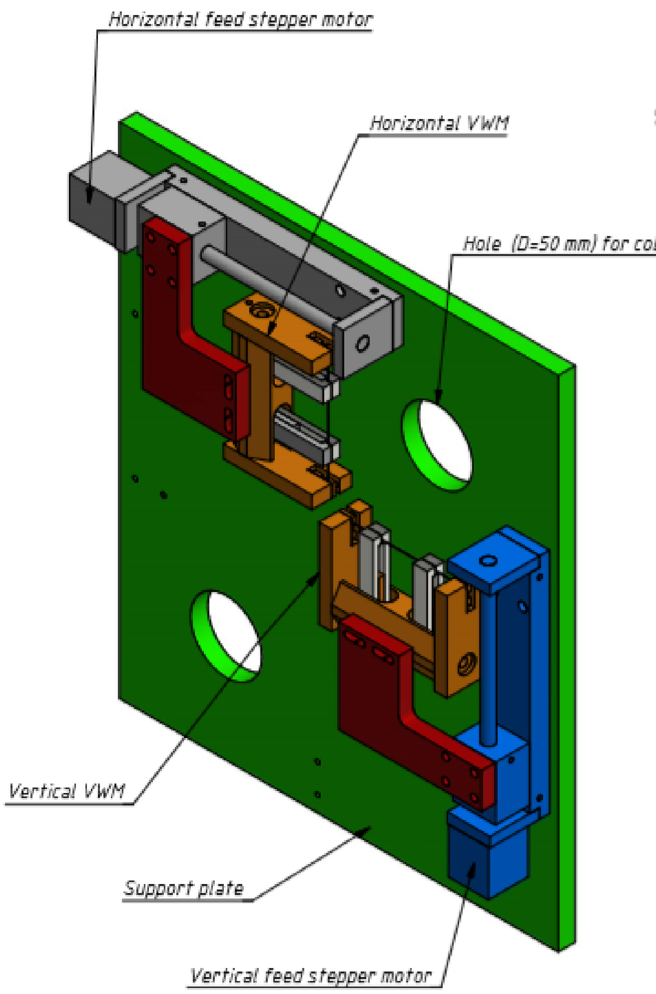
VWM Experiment Team at KOMAC

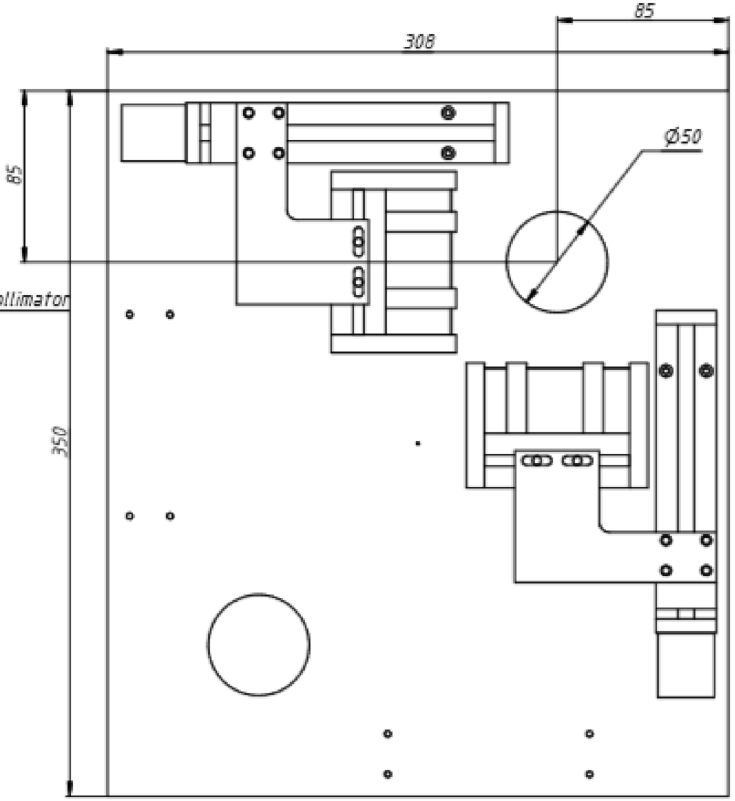
Beam line on Cyclotron side. 1 - IBA Cyclotron, 2 - vacuum valve cuts the cyclotron off from the beamline, 3 - bending magnet for beam positioning, 4 - collimator based on two eccentric drums (5) with vertical rotation axes, 6 - cube with pass-through flanges for beam (7 and 8), target placement system for beam guide (9), flange for target viewer (located on the side), flange for high-vacuum sensor (10), 11 - pair of quadropoles, 12 - gateway to the experimental hall.

Beamline in experimental hall. 1-the beamline coming from the cyclotron hall, 2 - neutron shutter (iron and nickel cylinder for absorption of residual neutrons, open during operation of the beamline, and closed during idle time so that neutrons do not flow from the cyclotron into the experimental hall), 3 - drive mechanism of neutron shutter with pneumatic cylinder, 4 - end switch of the drive mechanism, 5 - a pair of quadropoles, 6 - viewer for calibration (a cube to which both target viewer and vacuum pump and high vacuum sensor are connected), 7 - fluorescent target viewer for beam position calibration (feeded by pneumatic piston), 8 - vacuum valve, 9 - four jaw collimator for beam positioning, 10 - adaptor flangen flange, 11 - vacuum window, **12 - vibrating wire XY profiling station**

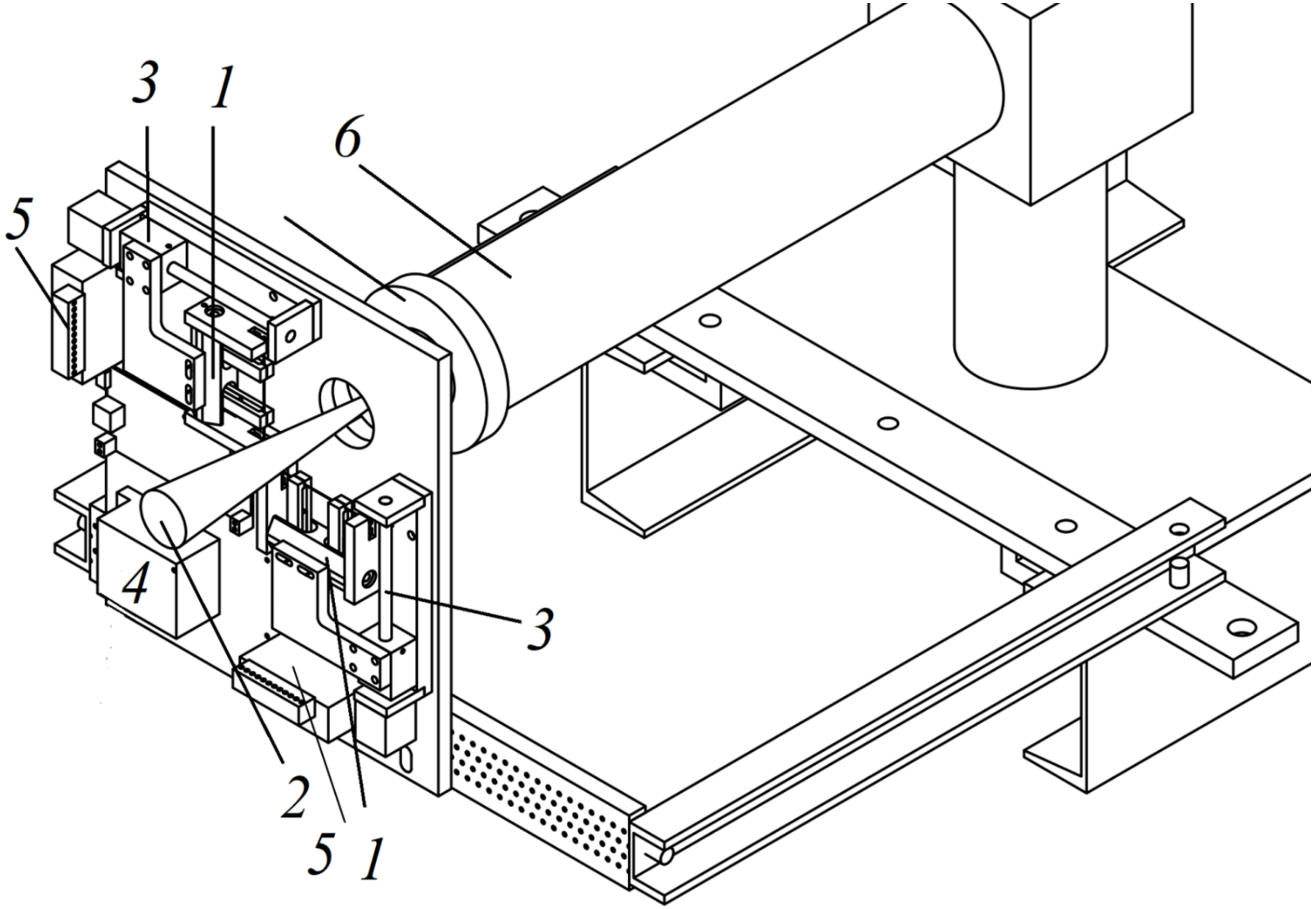


XY-VWM profiling station on Cyclotron C18





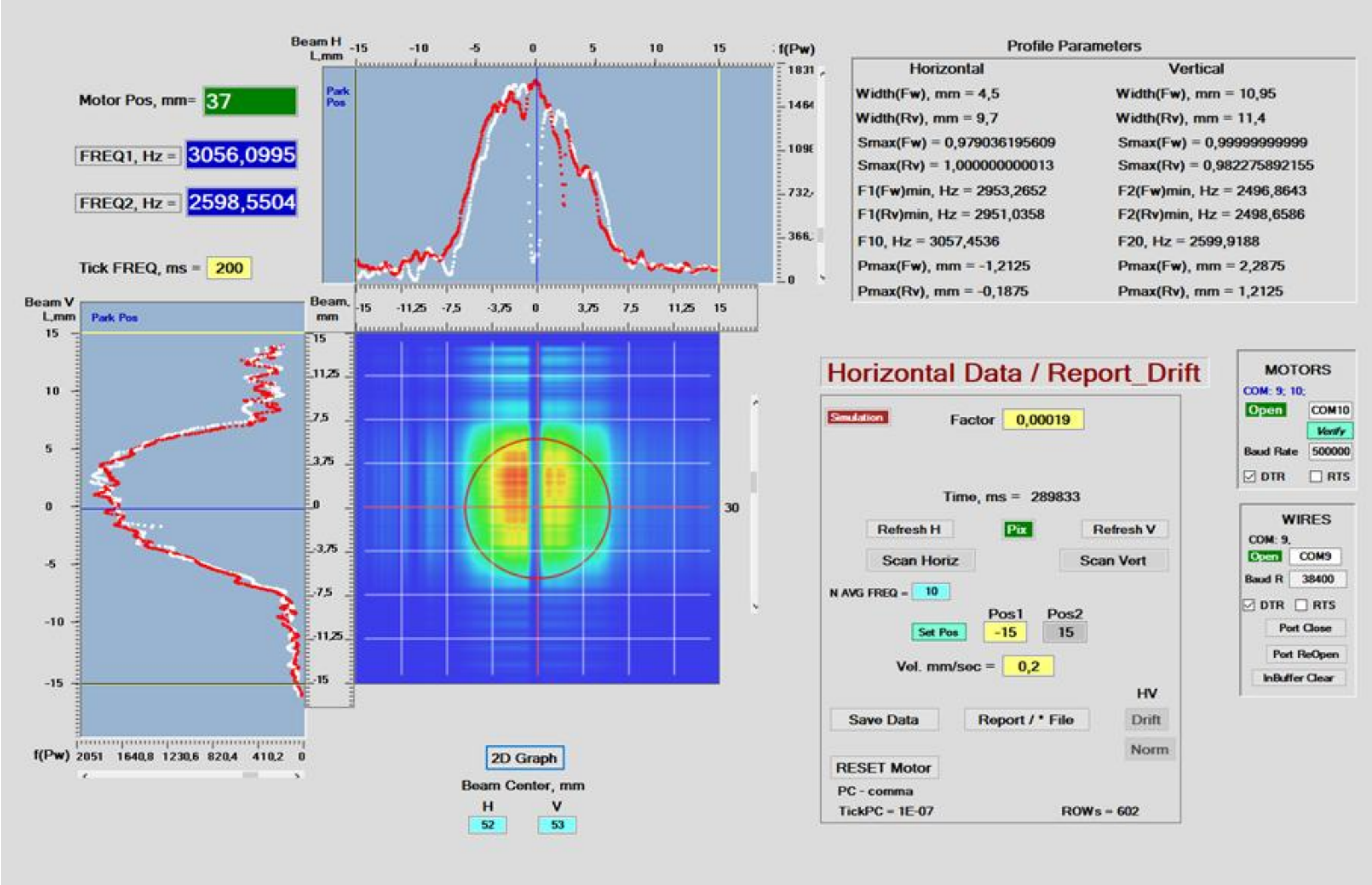
XY-VWM profiling station on Cyclotron C18



Profiling station installed at the proton beam outlet of cyclotron C18/18: 1 – vibrating wire monitors, 2 – proton beam, 3 – linear movement systems based on stepper motors, 4 – power supply , 5 – stepper motor drivers, 6 – beamline with flange – 7 at the beam outlet, 8 – electronic control board of the station, 9 – beam outlet system supporting channel bars, 10 – console construction for fixing the profiling station to the channel bars.

PC application

The profiles were reconstructed using a forward scan (from the park-position limit switch). No data processing was performed for the reverse scan. During the horizontal scan RF switch offs were occurred


Motor Pos, mm= 37

FREQ1, Hz = 3056,0995

FREQ2, Hz = 2598,5504

Tick FREQ, ms = 200

Profile Parameters

Horizontal	Vertical
Width(Fw), mm = 4,5	Width(Fw), mm = 10,95
Width(Rv), mm = 9,7	Width(Rv), mm = 11,4
Smax(Fw) = 0,979036195609	Smax(Fw) = 0,99999999999
Smax(Rv) = 1,000000000013	Smax(Rv) = 0,982275892155
F1(Fw)min, Hz = 2953,2652	F2(Fw)min, Hz = 2496,8643
F1(Rv)min, Hz = 2951,0358	F2(Rv)min, Hz = 2498,6586
F10, Hz = 3057,4536	F20, Hz = 2599,9188
Pmax(Fw), mm = -1,2125	Pmax(Fw), mm = 2,2875
Pmax(Rv), mm = -0,1875	Pmax(Rv), mm = 1,2125

Horizontal Data / Report_Drift

Factor 0,00019

Time, ms = 289833

N AVG FREQ = 10

Pos1 -15

Pos2 15

Vel. mm/sec = 0,2

PC - comma

TickPC = 1E-07

ROWs = 602

MOTORS

COM: 9; 10;

COM10

Baud Rate 500000

☑ DTR ☐ RTS

WIRES

COM: 9.

COM9

Baud R 38400

☑ DTR ☐ RTS

Beam Center, mm

H 52

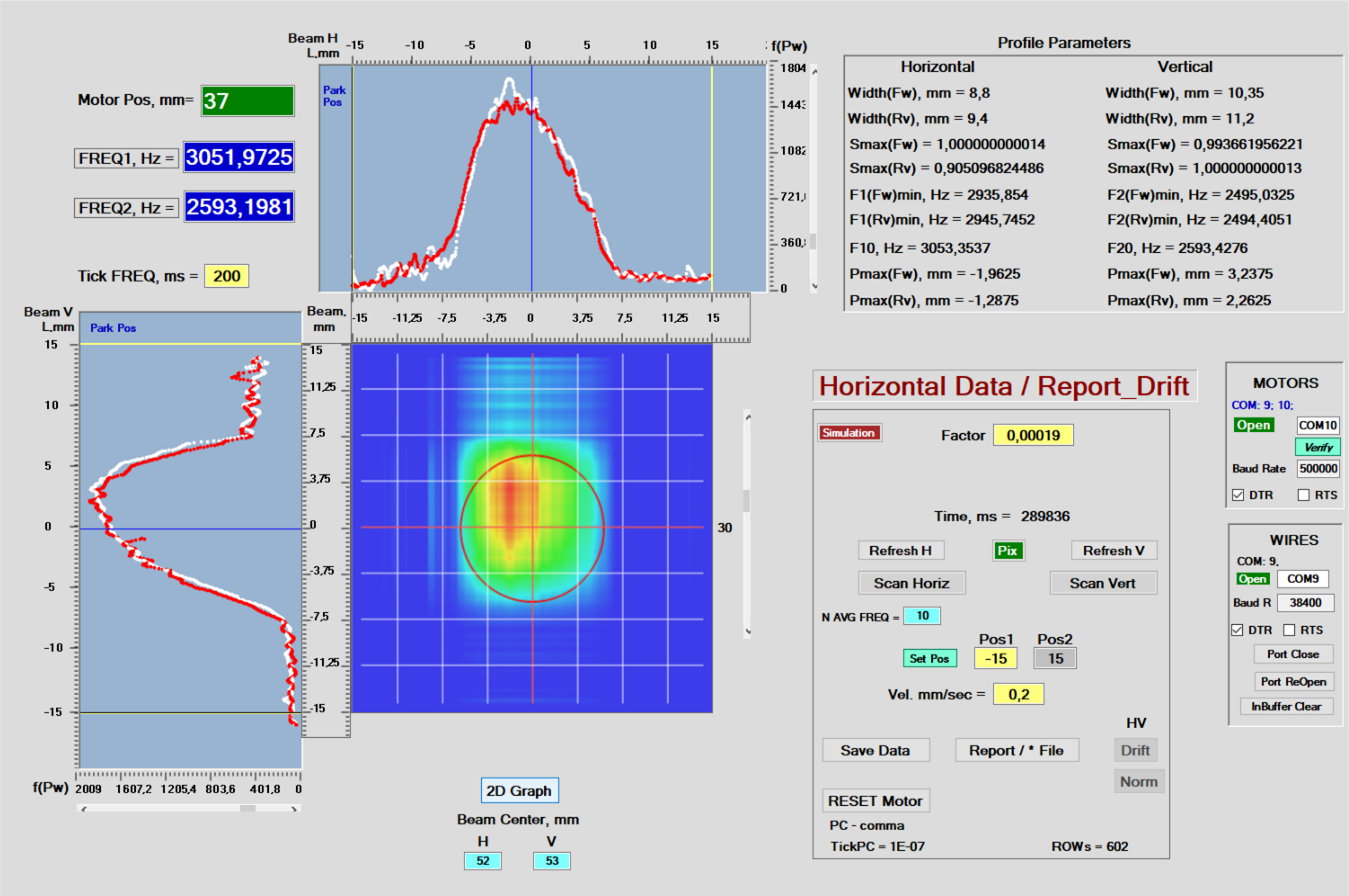
V 53

3 Attempt, 2023

OK

Horizontal:
DF_Fw =-115.7 Hz
DF_Rv =-103.8 Hz

Vertical:
DF_Fw =-99.9 Hz
DF_Rv =-100.7 Hz



Motor Pos, mm= 37
FREQ1, Hz = 3051,9725
FREQ2, Hz = 2593,1981
Tick FREQ, ms = 200

Profile Parameters

Horizontal	Vertical
Width(Fw), mm = 8,8	Width(Fw), mm = 10,35
Width(Rv), mm = 9,4	Width(Rv), mm = 11,2
Smax(Fw) = 1,000000000014	Smax(Fw) = 0,993661956221
Smax(Rv) = 0,905096824486	Smax(Rv) = 1,000000000013
F1(Fw)min, Hz = 2935,854	F2(Fw)min, Hz = 2495,0325
F1(Rv)min, Hz = 2945,7452	F2(Rv)min, Hz = 2494,4051
F10, Hz = 3053,3537	F20, Hz = 2593,4276
Pmax(Fw), mm = -1,9625	Pmax(Fw), mm = 3,2375
Pmax(Rv), mm = -1,2875	Pmax(Rv), mm = 2,2625

Horizontal Data / Report_Drift

Factor 0,00019
Time, ms = 289836
N AVG FREQ = 10
Pos1 -15
Pos2 15
Vel. mm/sec = 0,2
PC - comma
TickPC = 1E-07
ROWs = 602

MOTORS
COM: 9; 10;
COM10
Baud Rate 500000
☑ DTR ☐ RTS

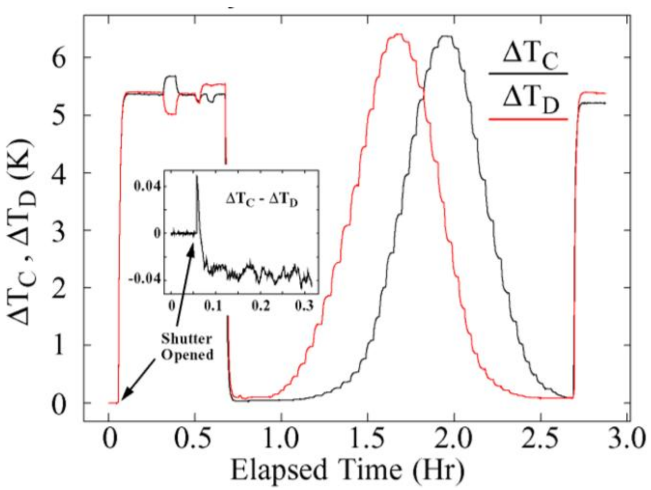
WIRES
COM: 9,
COM9
Baud R 38400
☑ DTR ☐ RTS

Beam Center, mm
H 52
V 53

VIBRATING WIRE MONITOR MEASUREMENTS OF A HARD X-RAY UNDULATOR BEAM AT THE ADVANCED PHOTON SOURCE

G.Decker, S. Arutunian, M.Mailian, G.Rosenbaum, DIPAC 2007.

Two horizontally- mounted 3.6-cm-long, 100-micron-diameter stainless steel wires with approximately 1.75-mm vertical separation



With the shutter closed, the fluctuations fall in the range ±0.001 K, while after opening the shutter with the beam approximately centered, the fluctuations are significantly larger,

For the insertion device tests, a total of 7 mm of Beryllium was placed in the measured radiation beam path, to limit the power striking the wires and to assure that only hard X-rays were being detected.

The field increases approximately exponentially as the ID gap is decreased to a minimum of 11 mm. The wire monitors first detected the beam at a gap of 80 mm, and registered a frequency shift of 1.5 / 2.0 kHz with a gap of 45 mm

With the detector installed in vacuum, the initial resonance frequencies f0 of the two wires were approximately 4005 Hz (wire C) and 5149 Hz (wire D)

The new “cold” wire frequencies were 4161 Hz and 5223 Hz, somewhat higher than at the start.

It is clear that the limitations of this device as tested are the slow response time and the power-handling capability.

As a hard x-ray detector, the VWM concept shows a lot of promise due to its very high sensitivity and overall simplicity in both the mechanical design and front-end electronics.

75 MeV LINAC (former Injector of Yerevan synchrotron)

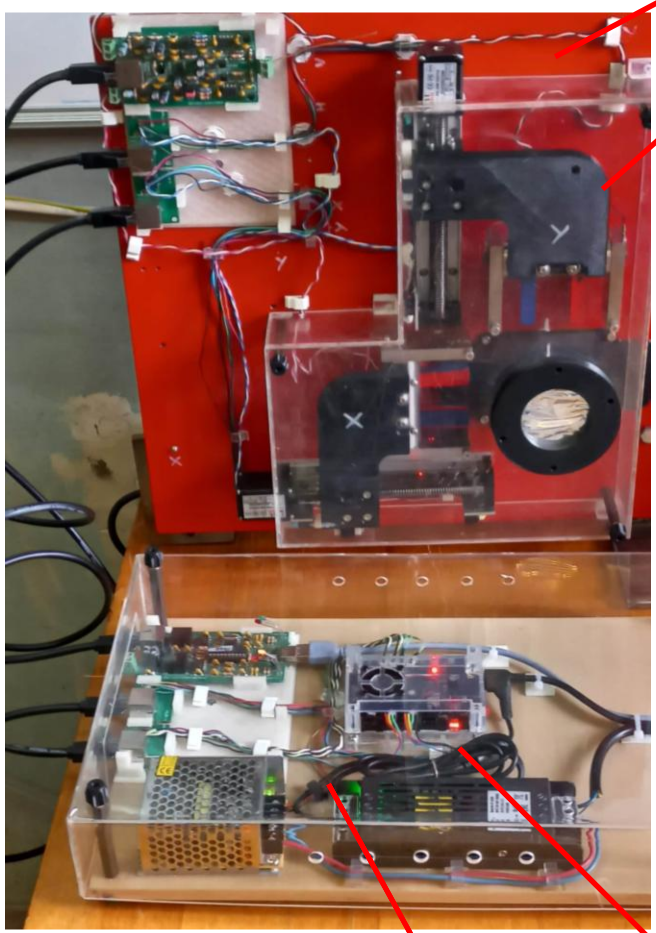
In presence

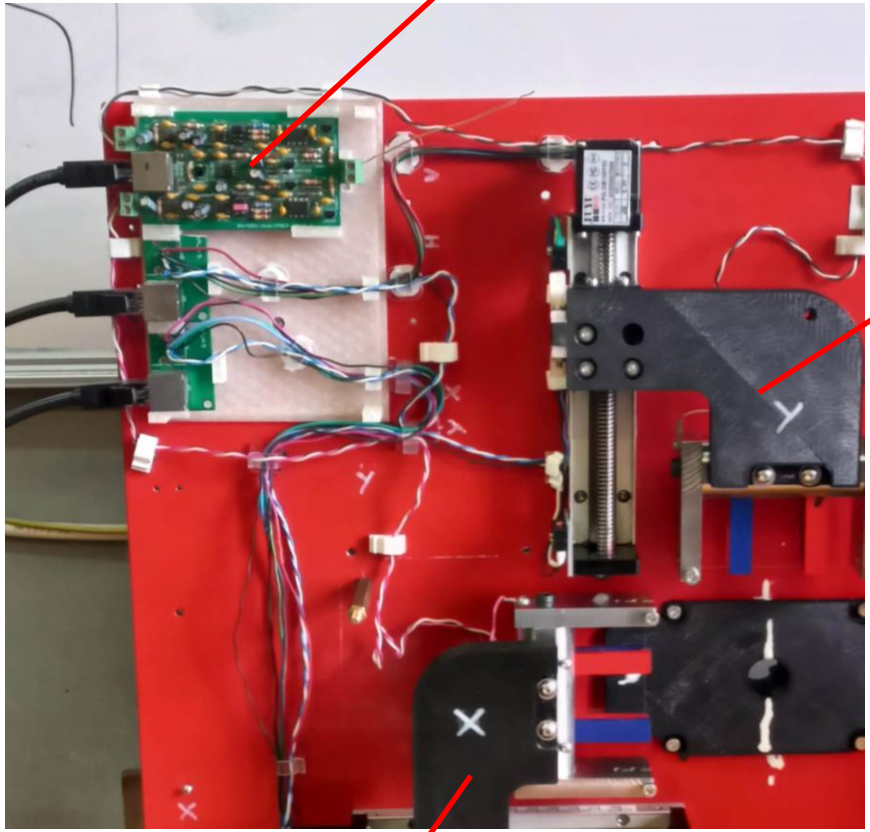
Accelerator side

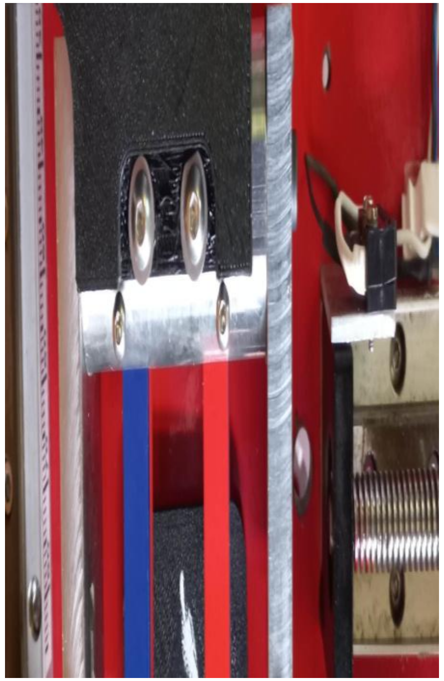
Anticonvection box

Front-end electronics

Vibrating wire monitor

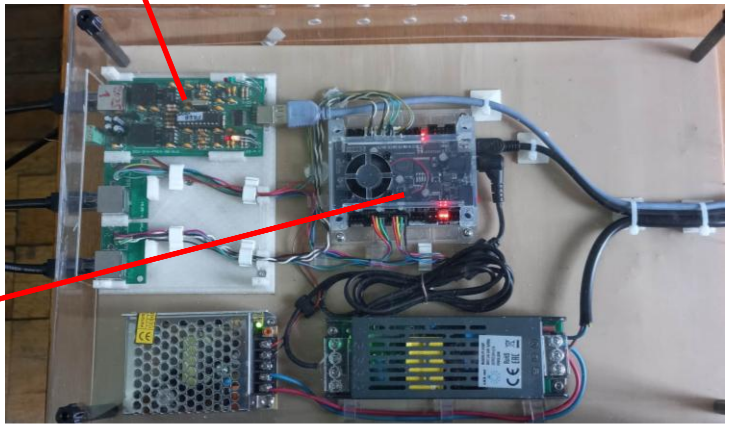






Y direction

Read-out electroncs



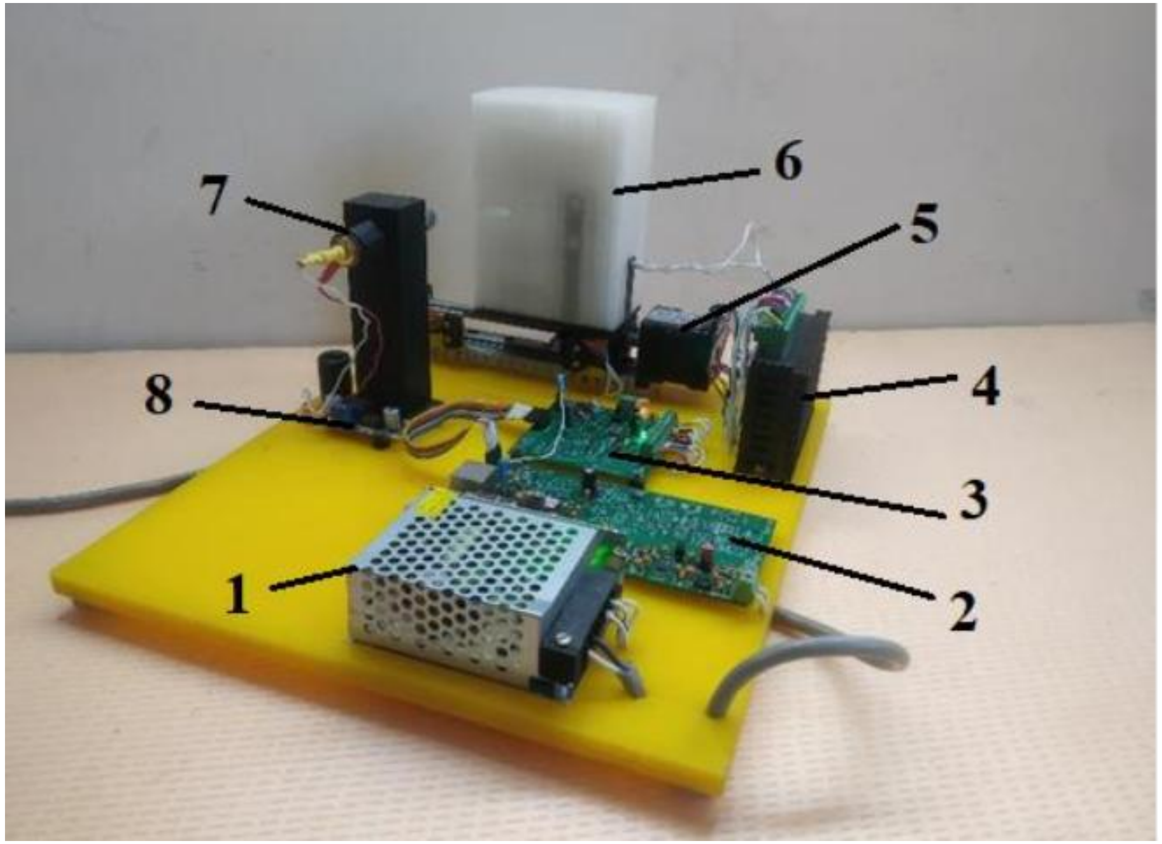
Control room side

X direction

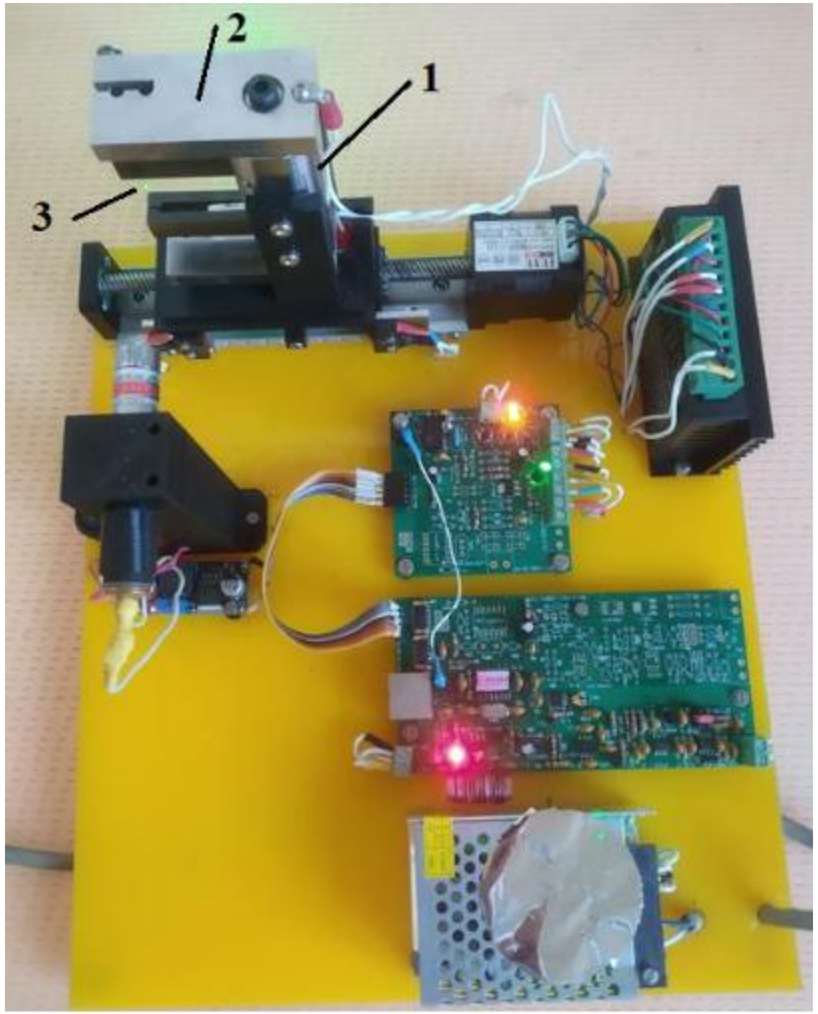
Stepper motor drivers

German-Armenian Student Course on Accelerator Physics

Since 2018, CANDLE Institute has been offering week-long laboratory courses on accelerator physics for students from the University of Hamburg and Yerevan State University. One of the topics covered in this course is [Vibrating wire monitors and beam profile measurements]

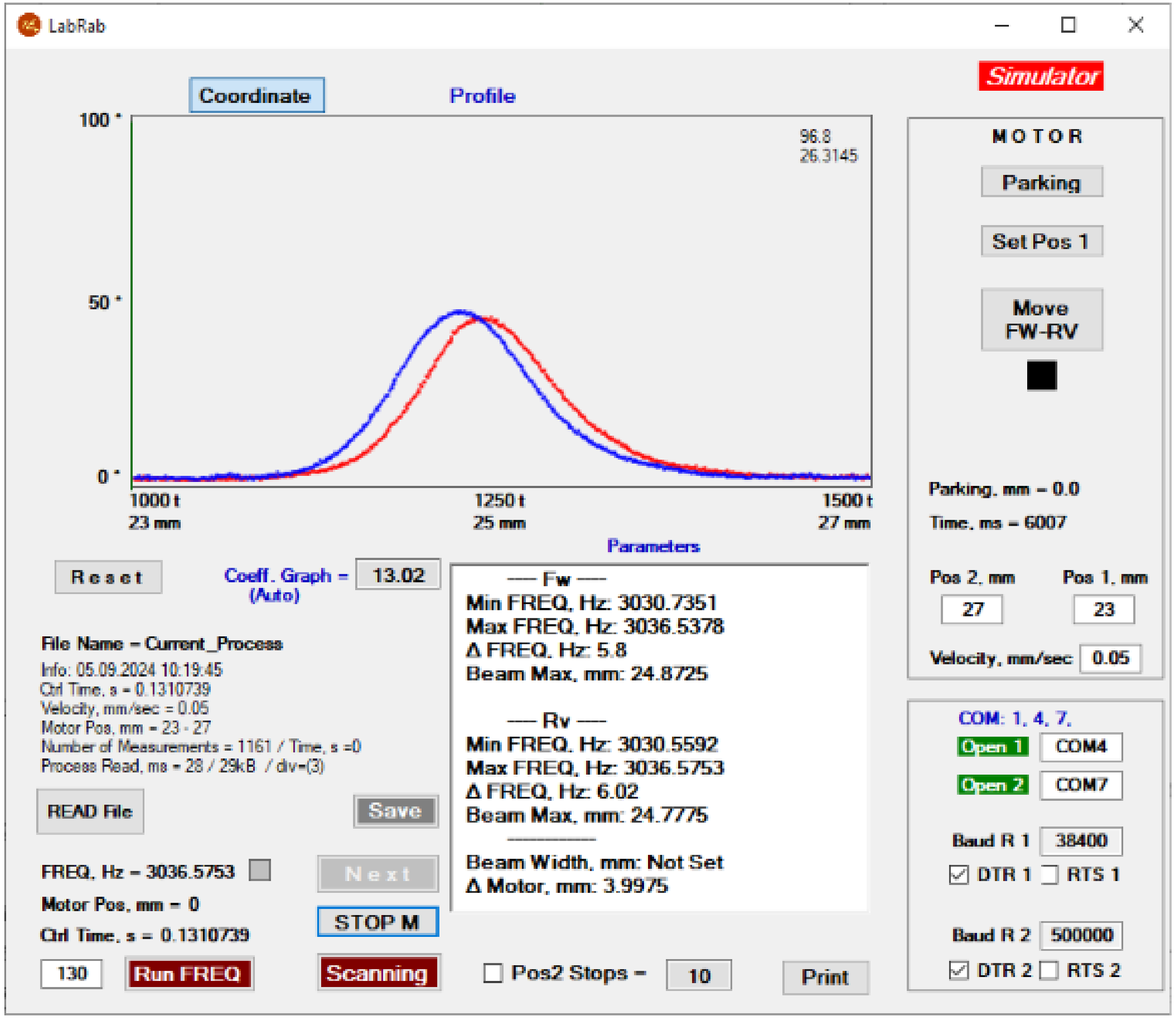


1 - Power supply, 2 - wire autogeneration board, 3 - step motor control board, 4 - step motor driver, 5 - linear actuator, 6 - VWM covered by anticonvection box, 7 - laser, 8 - laser supply



1 - VWM, 2 - VWM upper clips, 3 - laser spot on the vibrating wire.

Application for 1-D scnning of laser beam



Coeff. Graph = 13.02 (Auto)

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File Name = Current_Process
Info: 05.09.2024 10:19:45
Ctrl Time, s = 0.1310739
Velocity, mm/sec = 0.05
Motor Pos, mm = 23 - 27
Number of Measurements = 1161 / Time, s =0
Process Read, ms = 28 / 29kB  / div=(3)
```

```
--- Fw ---
Min FREQ, Hz: 3030.7351
Max FREQ, Hz: 3036.5378
Δ FREQ, Hz: 5.8
Beam Max, mm: 24.8725

--- Rv ---
Min FREQ, Hz: 3030.5592
Max FREQ, Hz: 3036.5753
Δ FREQ, Hz: 6.02
Beam Max, mm: 24.7775
-----------
Beam Width, mm: Not Set
Δ Motor, mm: 3.9975
```

FREQ, Hz = 3036.5753 ☐
Motor Pos, mm = 0
Ctrl Time, s = 0.1310739
130

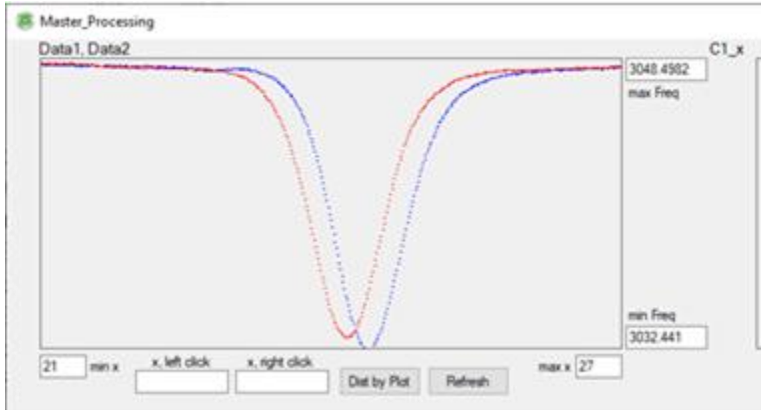
☐ Pos2 Stops = 10

Parking, mm = 0.0
Time, ms = 6007
Pos 2, mm: 27
Pos 1, mm: 23
Velocity, mm/sec: 0.05

COM: 1, 4, 7,
Open 1: COM4
Open 2: COM7
Baud R 1: 38400
☑ DTR 1 ☐ RTS 1
Baud R 2: 500000
☑ DTR 2 ☐ RTS 2

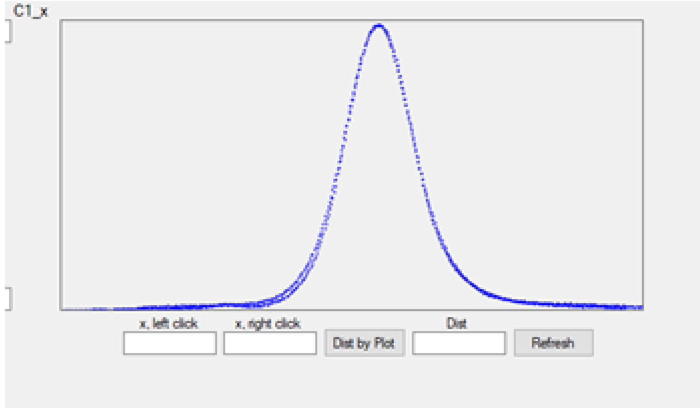
Application graphical interface

Data post-processing



3048.4582
3032.441
min x: 21
max x: 27

Raw data



Data normalization and one parameter
Regression based on forward and
backward scans

German-Armenian Student Course on Accelerator Physics

Prof Joerg Rossbach

Garni, I centure A.C.

Students and advisers

Gegard,
X centure

Expressive presentation by Louis Spottek

Prof Wolfgang Hillert

Director of CANDLE Bagrat Grogoryan
and Prof Rossbach

Typical parameters of VW resonators:

Length of wire, mm:	10..120
Used wire diameter, um:	10-200
Wire material:	Stainless steel
	Beryllium bronze
	Tungsten
Frequency range, Hz:	1000..8000
Frequency measurement resolution at 1 s sampling, Hz:	0.01
Quality factor, in air/in vacuum	few thousands (in vacuum)
VWM dynamic range	more than 1E5
Short time stability (few hours, with T correction)	0.01 Hz
Lifetime	>10 years

Weak dependence on the magnitude of the magnetic field in magnetic poles

VWM is robust and does not contain difficulties for manufacturing

The main electronic board is the analogous scheme of oscillations generation. All other electronic circuit can be done on modular principle

- frequency measurement unit
- end switches and stepper motor control
- interface with control room
- data acquisition and vizualization
- data processing and post-processing

The main limitation of the VWM it seems to be the slow speed of the profile measurement process—here, the solution lies in advanced mathematical processing.

Installation in a vacuum chamber requires a vacuum chamber connection tube of a sufficiently large size, since the sensor's length along the wire = aperture + magnetic field + clips ~ 3 times the aperture.

The sensor contains large components (base, clipses, magnet poles), meaning it must have a sufficiently powerful feed mechanism.

Despite its simplicity, VWM requires careful handling, as it contains narrow magnetic slots into which magnetic dust can easily penetrate, disrupting the conditions for oscillations autogeneration and stability.

Although the wire is typically quite thick (100 µm), mechanical damage to the wire also disrupts its oscillations autogeneration and stability

When working in the air, protection against convection is required—this is especially true in accelerator halls, where powerful ventilation is often present

VWM as resonant target

In the traditional method of beam profiling using a passive wire, the radiation or secondary particles generated by the scattering of the beam on the wire are measured. However, it is difficult to determine from the output signal of the measuring detector which part of the signal corresponds to the scattering itself and which part is due to the uncontrolled background.

We proposed using a vibrating wire as a target instead of a passive wire, and extracting from the detector signal only the portion that correlates with the wire’s oscillation frequency

The measurement algorithm proposed is based on subtraction of series of half-period measurements, which enables to eliminate background.

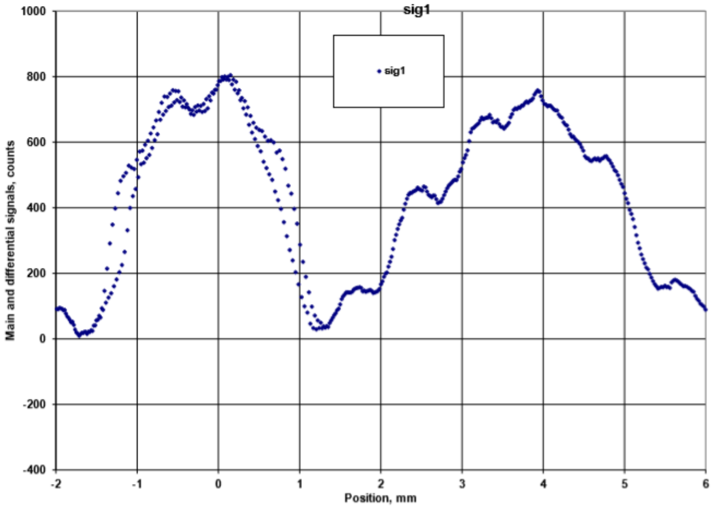
The implementation of the method was tried out only on a laser beam. A photodiode was used to measure the photons reflected from the wire. The algorithm described above was then applied to the results obtained.

$$g_i = k_1 * \begin{cases} [S_{i+1} - S_i], & i = 1,3,5,\ldots \\ -[S_{i+1} - S_i], & i = 2,4,6,\ldots \end{cases},$$

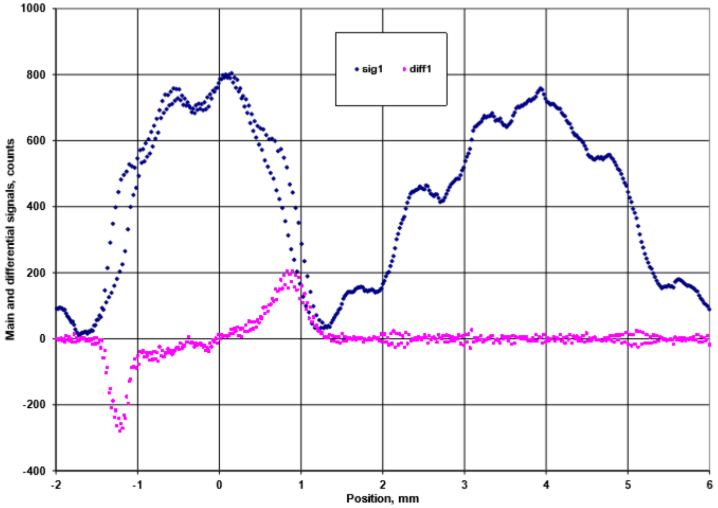
where Si is the subsequent half-period photodiode measurement.

Profile recovering

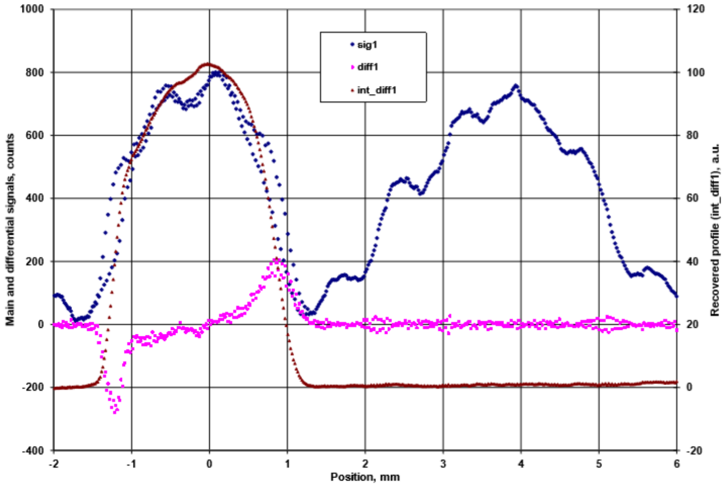
S.G. Arutunian et al., Fast resonant target vibrating wire scanner for photon beam, RSI 87, 023108 (2016).



photodiode measures reflections from both the vibrating wire and other mechanical parts of VWM



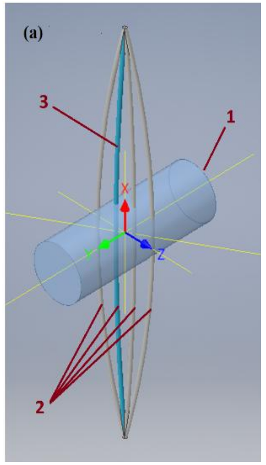
differentiation of photodiode signal (magenta)

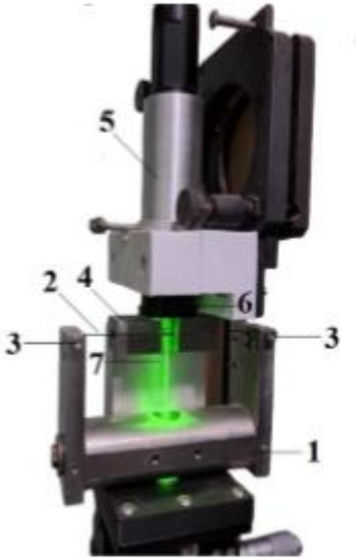


developed algorithm recovers the laser beam profile (brown)

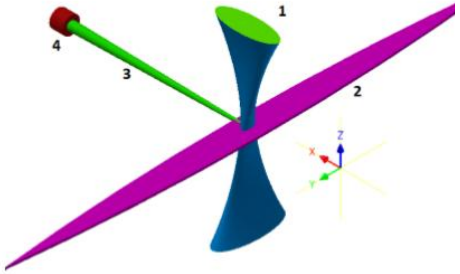
The average oscillation velocity of the wire reaches to 10 mm/s
Proposed method can be applied up to 10 mm/s and more
See [M. A. Aginian, G. S. Harutyunyan, S. G. Arutunian, S.A. Badalyan, 3 M. Chung et al., Development of New Algorithm in the Method of a Resonant Vibrating Target for Large Scanning Speeds, Journal of Contemporary Physics (Armenian Academy of Sciences), 2019, Vol. 54, No. 3, pp. 232–241

VWM as miniature scanner





Formal pictures

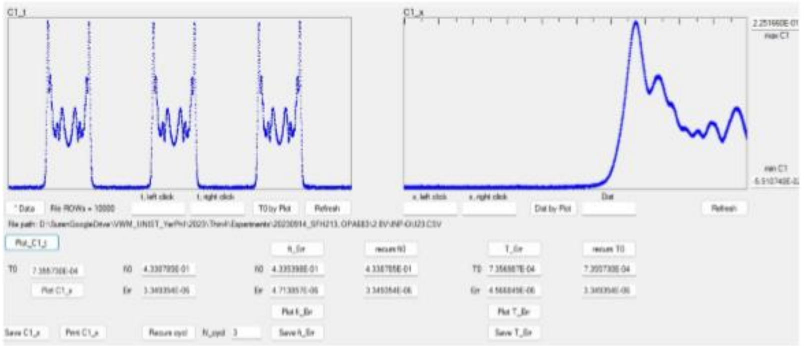


Blue – laser beam focused
Magenta – area of swept by wire
Green – reflected photons
Brown – fast fotodiode (ns range)

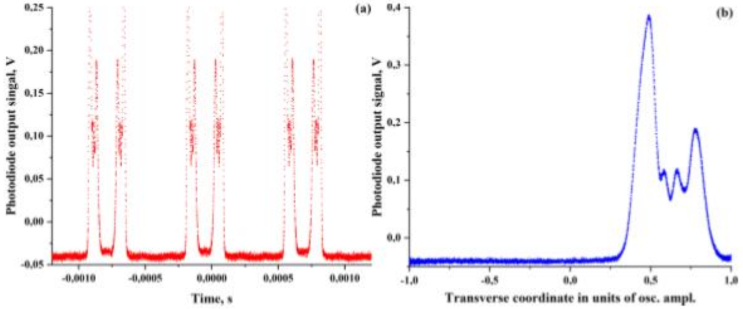
S.G.Arutunian et al., Characterization of a thin laser beam profile by a vibrating wire with fast electronics and new data processing algorithm, 2025, JINST, 20, T07001

We have no information concerning amplitude and phase of wire oscillations

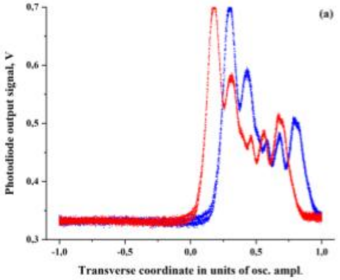
In first step we tried to use information concerning frequency, but usually we use only few periods of oscillations. Now we obtain all necessary information from photodiode data



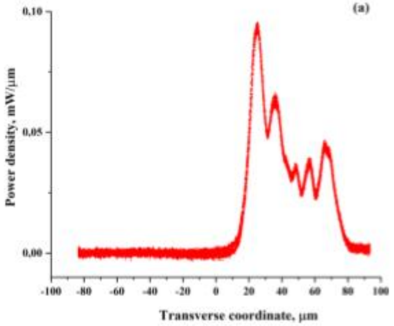
2 parameter recursive fitting algorithm allow us to obtain period of oscillation and phase



Raw data and reconstructed profile in terms of oscillations amplitude



Relative coord



Absolute coord

Next plans:
1. Thin beam tomography
2. To adapt to charged particles

Monitoring of structural changes in materials of vibrating wire

Monitoring of structural changes in materials is an urgent task. Let us emphasize the field of nuclear power engineering, in which the factor of changes in the structure of materials is the presence of intensive neutron irradiation.
Such irradiation for a long time strongly affects the mechanical properties of the nuclear reactor vessel etc

Impact of radiation on the resonant frequency of a the key factor is the tension in the wire, which is determined by elastic modulus of the wire material E

$$F = \frac{1}{2L}\sqrt{\frac{\sigma}{\rho}} \qquad \sigma = \frac{L - L_0}{L_0} E$$

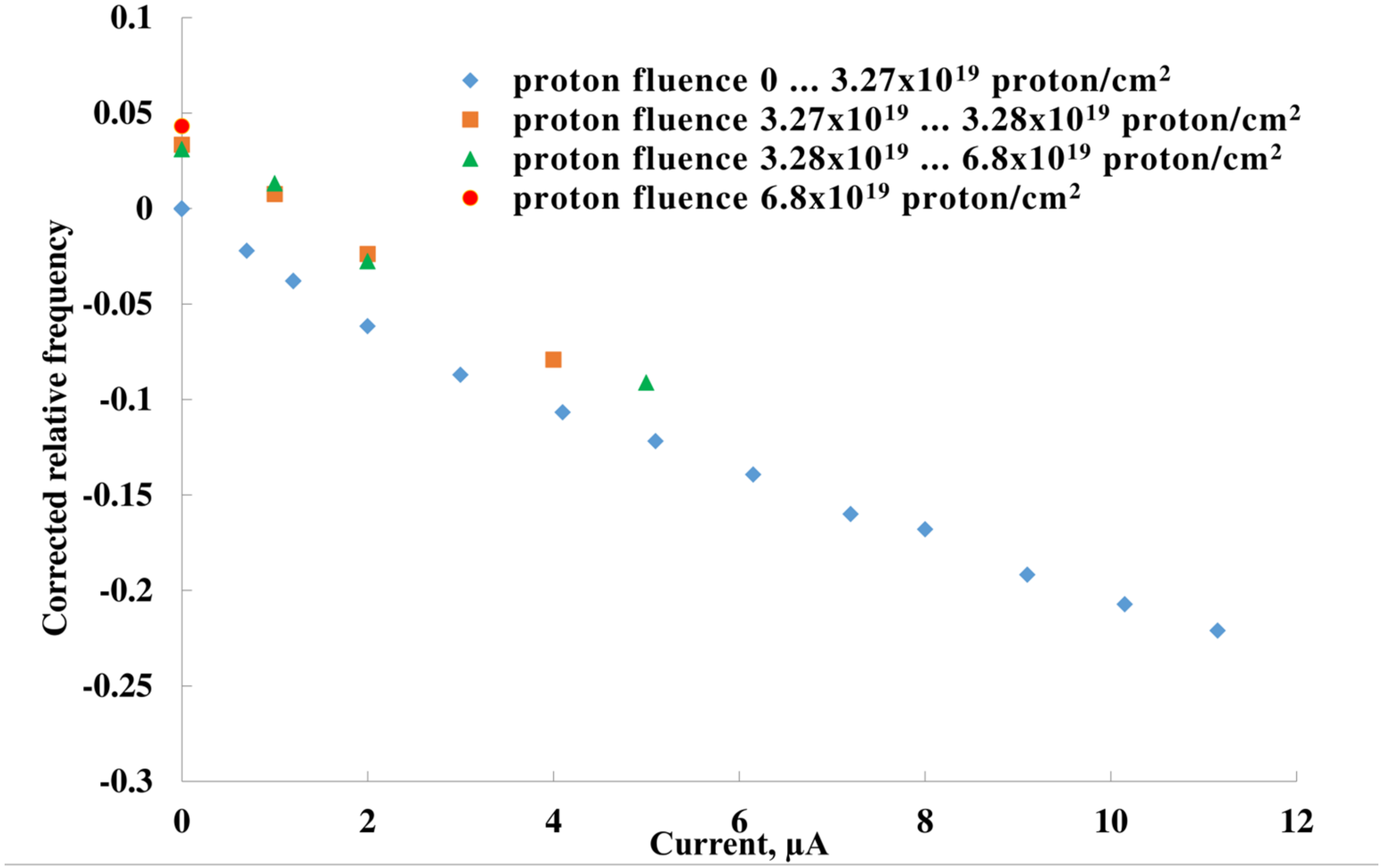
L_0	Length of unstressed wire
L	Length of wire tensioned in clips

Three methods were used to modify the structure of the string material
Load exceeding the elastic limit
The effects of short, high-power electrical pulses
The effects of long-term exposure to ionizing radiation

The prospects here lie in the use of composite wires and usage of various materials

Exposure of 18 MeV proton beam

S.G. Arutunian et al., Monitoring of structural changes in materials under the exposure of ionization radiation using a vibrating wire, RPC, 242, 113651, 2026



In the case of irradiation with a proton beam with an energy of 18 MeV and a fluence of up to 6.8 ×10^19 proton/cm2, a residual change in frequency of more than 4 % was observed, which is significantly greater than the frequency stability level in vibrating wire monitors.

Thank you, and thanks also to all my colleagues.
I would especially like to thank Professor Moses Chung for his kind invitation to visit beautiful Korea, especially during such a wonderful time of year

정말 감사합니다

gamsahabnida