Measuring carbon fiber aging on orbit

Bc. Martin Urban[1], *Bc. Veronika Stehlikova*[1], *Bc. Ondrej Nentvich*[1], *Ing. Ladislav Sieger, CSc.*[1] *and Kazuo Yana.*[2]

[1] Czech Technical University in Prague, Prague, Czech Republic

[2] Hosei University, Koganei City, Tokyo, Japan

***Abstract* - This paper describes the outcome of internship at the faculty of science and engineering, Hosei University in summer 2014. The goal of the project is to design a measuring system of aging properties of a carbon fiber reinforced composite in space. The project is a part of the nano-satellite project at Czech Technical University in Prague, scheduled to be launched in 2016.**

The measurement environment in space is different from the standard measurements performed on the ground in laboratory. The system design specification has a large constraint in size, weight and power consumption by the limit of space probes. To meet these requirement, the basic measuring system of the mechanical damping characteristics of the carbon fiber composite is designed in this internship project. A damping oscillator to simulate the response of the target material has been assembled and measuring parameters are optimized. The optimized algorithm has been implemented in the chip to be launched on the space orbit.

I. PROJECT QB50 AND PROBE VZLUSAT1

During our internship at Hosei University we were working on CubeSat project QB50 concretely on the probe VZLUSAT1. This project runs under the auspices of Czech Aerospace Research and Test Establishment (VZLU) and Czech Technical University in Prague (CTU). In this project also cooperates many other companies, for example, Rigaku Innovative Technologies Europe, s.r.o., 5M s.r.o., TTS s.r.o., Innovative Sensor Technology s.r.o., DENTEC and with many other individuals and specialists.

The goal of it is to carry on the orbit a nanosatellite, which will perform diverse experiments. The QB50 project relies on building satellites of defined measures, based on cubes 10x10x10 cm, which can be combined up to three cubes in a row for one probe this time. In the future should be constructed bigger satellites up to 2x2x3 units. Their conformity allows to carry a large number of different probes to the orbit together. The reason of the project's name is, that there will be space for 50 units of two cubes (2U) standardized units aboard. One of each 2U have to had maximum power supply up to 2 Watts and up to 2 kg.

The philosophy of this project is, to make a path for cheaper and easier manufacturing of satellites in the future. To build and carry a satellite to the orbit is not a cheap thing, so it is the reason why even on high-end projects are still used old verified materials and technologies. They simply are proved by time and the project sponsors do not want to risk using any new and untested parts, due to which the whole project could crash.

Compared to these large, separate projects, the SpaceCube program offers an opportunity for lots of scientist, who need to test something new on the orbit without risking lots of funds. These small satellites are carried on next to a main standard satellite, a little bit like a stowaway, which is the carrier primary used for. So these nanosatellites like SpaceCube are depending on projects of standard space research, without the possibility of an independent start. As a small satellite, it does not have own active power also.

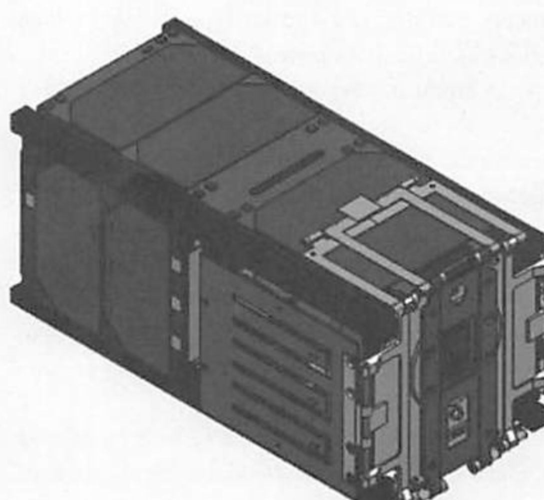

Fig. 1: Appearance of the cube sat VZLUSAT1

In general, the main part of people working on SpaceCubes recruits among the college students and their mentors. It is a chance to work on an interesting project with a possibility of future extension. It is our case too. After the launch, we will cooperate with University of west Bohemia, in Pilsen, where will be the headquarters for communication with orbit. We will get the raw measured data from them that we will process into final results.

II. VZLUSAT1 IN GENERAL

Project VZLUSAT1 carries ten experiments in total. These experiments have various aims. There are two main tasks on the satellite. One tests a new carbon fiber reinforced composite panel with metallic coating made by 5M and TTS companies for utilization on space probes from the perspective of strength, weight, radiation shielding, durability and evaporation, the second one is Wide-angle X-ray imaging system.

Examining of this composite panel could lead to verification of suitability for this kind of material, which, if it pass, could be used as shielding material for standard satellites e.g. GPS and communication satellites, etc. in the future. Naturally, due to the rising popularity of this cheap nanosatellites like type QB50, this proved material could be used for producing standardized parts of skeleton and shielding for them too. It means an advantage for future experimentators, who will be able to fully concentrate to their research itself, without solving questions of construction and shielding.

Wide-angle X-ray imaging system with Timepix detector is a special type of lens, which works with reflexivity instead of refractivity.

Because the probe doesn't have active engine, there are at least coils for all three dimensions, which will slightly orient the probe in dependence on Earth's magnetic field.

One of next parts of measuring is measuring of humidity. There will be several sensors in the probe, which are connected with the main computer through I^2C. The computer has to be programmed to switch between desired sensors and get measured values.

Last but not least of our tasks is measuring of space radiation and shielding capabilities of composite panel. The probe will have three measuring diodes aboard and they will be shielded by none, one and two layers of composite. This task is complicated due to low sensitivity of diodes in case of high temperatures, and cooling in free space is hard to solve. There also is a problem with additional radiation from inside, from irradiated construction of probe; there will be not only measured signal from space, but this unwanted radiation too. It is necessary to try to separate both environments or subtract it for relevant results.

Space cube carries also many other tasks. For example, there will be sensors for measuring temperature in different parts of probe, or humidity sensors (made by Innovative Sensor Technology s.r.o.), which will measure vaporization rate of tested composite during transition from atmosphere to vacuum. These tasks don't have so high importance and due to the power limitation of whole device they run only when main tasks are switched off, like in case of Timepix doesn't look into the Sun. That means, all tasks are sharing processor time as in time multiplex and have solar and backup battery power together.

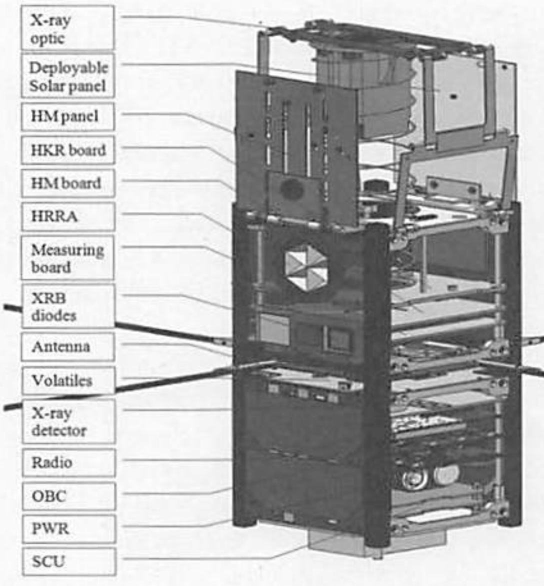

Fig. 2: Measuring boards and inner arrangement

Measured data will be sent to the headquarters in Pilsen when the probe will pass over Czech Republic. It will be approximately twice to day. The speed of data transmission will be changing as well as the time go. Data amount depends on where the probe will be and how long can communicate according to height of orbit where the probe will be. The height of the orbit will reduce over time and data speed will be slower. Due to limited volume of data which is possible to send, is necessary to process raw data on orbit and let to the Earth arrive only results.

Carrier with our VZLUSAT1 will start January 2016 from Brazil, with an Ukraine rocket. It will be brought to low orbit, 350 km high. Then it will collect data at least two month. It depends on how lucky will the probes be during the launch, in case of a great starting angle, it could work half year too. Of course, there are many other possibilities, which can involve lifetime of satellite. It is not sure how well will it deal with temperature changes on orbit, with radiation exposure and other unexpected conditions. Whole time it will send data to the Earth and in the end, space probe will burn in atmosphere.

INTERNSHIP AT HOSEI

I. SUMMARY

Our work comprises technical solution of measuring aging of carbon fiber reinforced composite, and as an usual projects at CTU, it is quite complex. It begins from theory, mathematical and physics modeling and working out the tasks in simulation programs. Then there is a part of trying to apply proposed resolutions on testing facilities, only to check the possibility in real situation. Simulations, include these with high sophisticated software, still cannot cover the entire range of possibilities that may affect the device as a whole. If the device on a breadboard or testing board works, a printed circuit board proposal follows. Last task is to assemble the final version, last testing and then the device can come to mass production or to science use, as in case of our probe.

II. MAIN GOALS OF OUR EXPERIMENT

Whole our work was divided into several parts following one after another. First we had to design printed circuit board for main measuring. This is first step because one testing board must be produced and proved in many tests before the launch. At the moment when design was completed we can start design and write a program for measuring changes in the resonant frequency (due to composite aging).

The main goal is to create and write a program for microcontroller which will measure signal with unknown frequency in range 100-200 Hz (composite material's resonance frequency) by Fast Fourier Transform with the highest possible accuracy in frequency and resolution approximately 0.1 Hz. Another purpose is calculating exponential envelope damping factor. Microcontroller should be able to communicate with on board computer (OBC) via I^2C interface. Next goal is measuring temperature by I^2C thermometer, radiation and evaporation.

Measuring evaporation other gas from the material will ensure by five humidity sensors. These sensors are not only sensitive to humidity but also on some other gases which may be released from the material. To check the will be placed several different types of sensors in the probe. For these sensors was necessary to design the PCB (Printed-Circuit-Board) too.

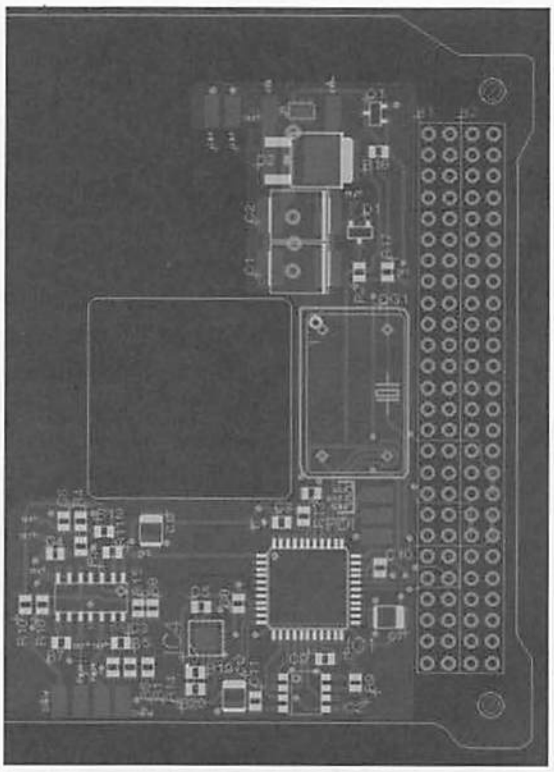

Fig. 3: Printed circuit board for the measurement

III. INPUT SIGNAL

Input signal is measured by piezoelectric element glued on composite plate and has approximately exponential envelope modulated by material resonance frequency. Exponential envelope is caused by attenuation in the material. Useful signal length depends on attenuation, which is caused by physical dimensions and material properties in the material and amount of energy excited by coil. In the picture fig. 4 is shown one example of input signal. Measured real signal has total length 0.9 s.

Input signal is sampled by 8 kHz. In case of computing attenuation (envelope) is used all signal for the better resolution in time. This signal is averaged by moving averages. Smoothed result is logarithmed and attenuation is directive of the course.

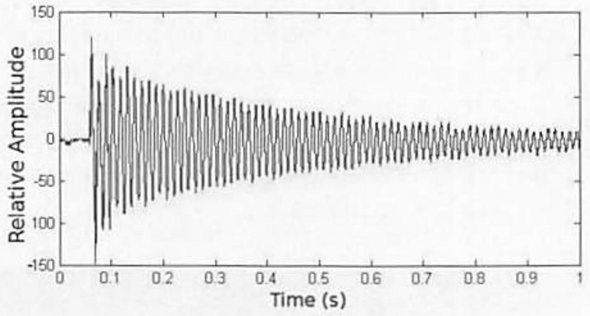

Fig. 4: Measured real damped signal

Resonance frequency is computed from decimated original signal using Fast Fourier Transform. If we use only FFT on the original signal we can calculate only with 1024 points (length of window) because we are limited by memory size installed in the probe. Computing by this process has final resolution more than several Hertz. What is a reason why we used decimation from 8 kHz to 500 Hz? The result of resolution is sufficient for us up to 200 Hz and sample frequency 500 Hz passed Shannon-Nyquist sample theorem with enough reserve.

This theorem says minimal sampling frequency must be two times higher than maximal measured sampled frequency.

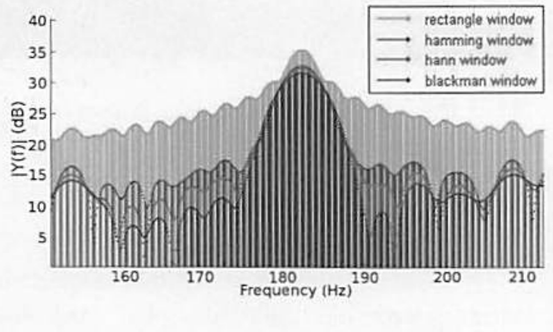

Fig. 5: FFT results with window length 4096 samples and different types of windows

Results for FFT with signal sampling 500 Hz and window length 1024 are better than previous one, resolution is 0.5 Hz, but it is still not enough. (Required is approx. 0.1 Hz.) This limit of calculation allowed us to save memory and to use larger window. We made interpolation with help of adding zeros behind the signal into expanded window with window length 4096 points. Resolution of the decimated signal to 500 Hz with these calculation parameters is approx. 0.12 Hz according to formula (1). Implemented measurement in the program aboard the probe, must sample signal just only once, so it leads to choose higher sampling rate and then apply decimation on signal to requested sampling rate. All these computations were simulated in MATLAB.

$$\Delta f = \frac{f_s}{n} \tag{1}$$

IV. Calculation process

Main process consists of several functions. Here is a brief list:

Sampling and storing data

The analog to digital converter included in microcontroller could sample signal up to two million samples per second. So it leads to averaging four-points groups to eliminate glitches. All data are stored into SPI SRAM memory from which are further loaded.

Computing damping envelope

First what is needed to do is to perform mathematically absolute value to get one sided envelope. Next step is logarithming signal because it is needed to get attenuation, which represents b in exponential expression as shown in formula (2). Then is applied moving averages to smooth signal and computing directive using least squares method.

$$f = A \cdot e^{-bt} \tag{2}$$

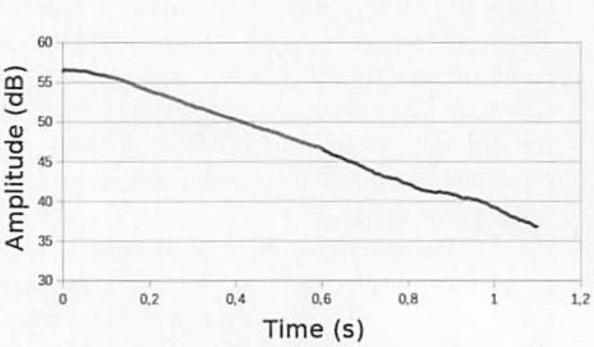

Fig. 6: Attenuation computed by least squares

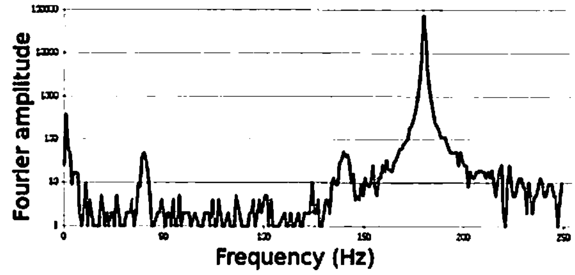

Fig. 7: FFT result by development kit

Computing Fast Fourier Transform

It is known, that resonance frequency of new material is in range 100-200 Hz so the signal sampled by 8 kHz must be decimated to 500 Hz to observe condition of the highest accuracy in frequency. FFT algorithm decimation in time is calculated in two steps. First step is to swap sampled points according to address which is bit reversed and next step is calculating Fast Fourier Transform. Program performs decimation and bit-reversing simultaneously. Program chooses one point and stores it to the bit-reversed address into SPI memory. Right address positions are stored in the table. Computation process picks up two points from memory, performs FFT algorithm and stores new points on the original positions. After that program finds the highest peak which corresponds with resonant frequency.

Store results into memory for further dispatch to the Earth

Results of attenuation and resonance frequency are stored into internal EEPROM memory of microcontroller for further dispatch to the Earth. Memory can include data amount which corresponds 40 hours of recording and hold data also after power loss.

V. Functionality Verification

During writing a program for development kit was necessary to check all functions. It leads to create device which one generates approximately the same signal as it gets from oscillations on the probe. With this idea came professor Yana who provided us draft of schematic, which is redrawn by Eagle software illustrated in the picture fig. 8.

The circuit produces oscillations with exponential envelope. To the circuit must be connected external oscillator as input of the board.

The board consists of some parts as monostable gate, output is connected to analog multiplier through capacitor which produces exponential envelope. To the multiplier is also brought external oscillator. Both inputs are multiplied in integrated circuit AD633. Output is connected to adder with another input from potentiometer which provide DC offset. Output of the board should be DC shifted in range +/- 15V. The board has power supply +5V and converted to +/-15V through DC/DC converter. Output voltage damped oscillations depends on voltage of oscillator and envelope.

Final board is in the picture fig. 9. Professor Yana was benevolent and arranged produce at manufacturer who create some pieces of boards which we assembled from parts who gave us. We are very pleased to create and then testing

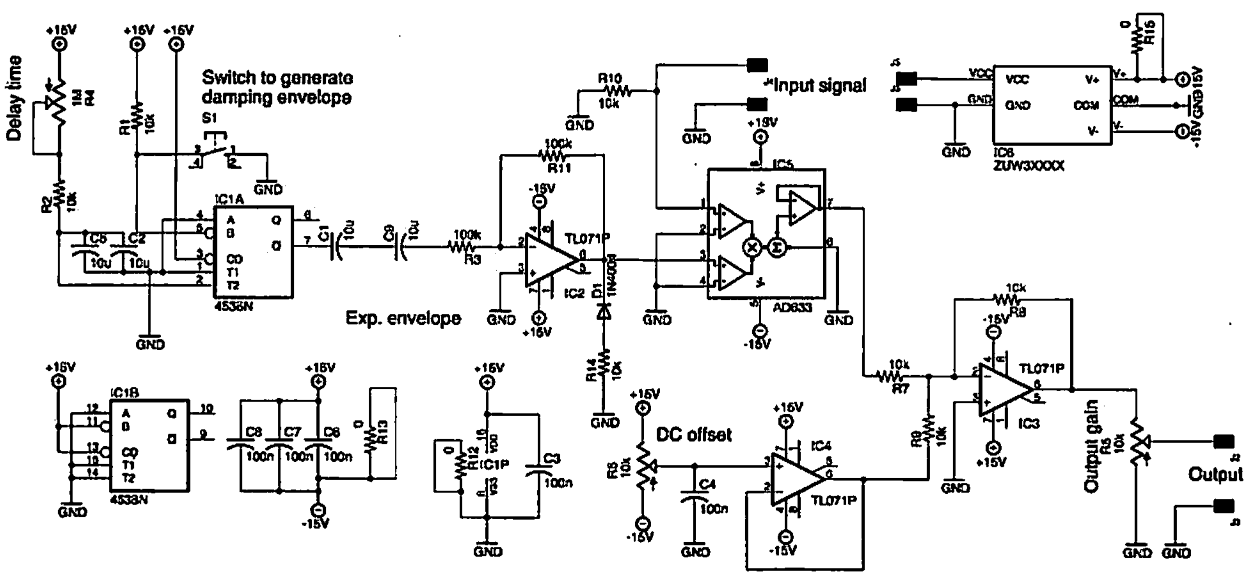

Fig. 8: Damping exponential envelope generator - schematic

on it damping oscillations measured by development kit.

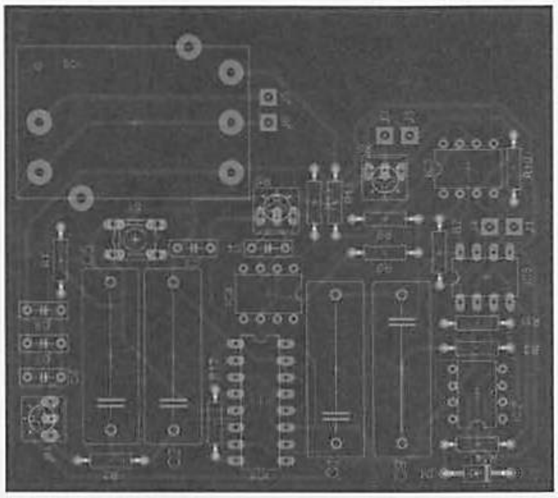

Fig. 9: Damping exponential envelope generator – Printed circuit board

The whole board was assembled and tested under supervision and technical assistance of Mr. Saitoh and Mr. Iki. They kindly provided us their laboratory with all necessary equipment like oscilloscope, signal generator or soldering station. Final assembled board is in the picture fig. 10.

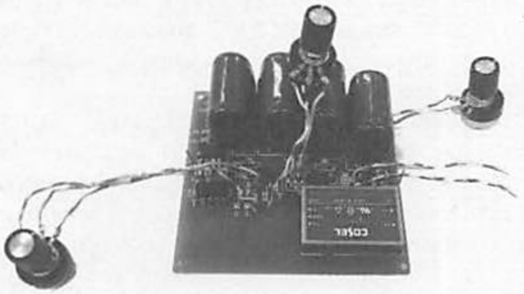

Fig. 10: Assembled damping oscillator

VI. Conclusion

During our internship we collaborated mainly with professors Kazuo Yana, Gaku Minorikawa and Akira Yasuda. These professors helped us to realize internship and during the whole summer helped us not only with the project but with staying in Japan too. Thanks to them we have progressed with our project and got great experience of Japan too.

Project VZLUSAT1 with cooperation VZLU consists of many measurements. One is measuring of material aging in the space. Measurement consists of exciting carbon fiber reinforced composite material by coil and measuring vibration by piezoelectric element. Damped signal with exponential envelope is sampled by microcontroller and then are calculated resonance frequency and damping factor. Using mentioned process is possibly to get final frequency resolution approx. 0.12 Hz. Every results as resonance frequency and damping factor as humidity and radiation are stored into memory and then are dispatch to the Earth during contact twice per a day.

Space probe CubeSat with name VZLUSAT1 will by launched in January 2016 and is funded by grants Technology Agency of the Czech Republic TA04011295 and TA03011329.

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Contacts

M. Urban, urbanm24@fel.cvut.cz
V. Stehlikova, stehlver@fel.cvut.cz
O. Nentvich, nentvond@fel.cvut.cz