ISSN 1392-2114 ULTRAGARSAS, Nr.2(55). 2005.

The informativity of the received signal exciting a circular resonator by bursts

V. Sukackas

Kaunas University of Technology, Physics Department
Studentu Str. 50, LT-51368 Kaunas

Introduction

It is usually important to determine the pipe sectional area and liquid flow decrease or medium layer thickness and heat transmission decrease measuring the sediment layer thickness in pipes. For this purpose the method that can give the evaluation of integral sediment thickness in the cross-section of the entire pipe during one or several measurements must be used. Lamb waves longer than maximal thickness of the sediments were used for this purpose. Waves were excited by the point-type transducer and received by another identical transducer, in the most common case attached exactly on the opposite side. Pipe works there as a circular resonator. The frequency response (ADCh) is measured slowly changing the frequency. Theoretically it must consist of equidistant resonance pikes and their relative width is related to the wave damping and at the same time to the amount of sediments. But usually ADCh is much distorted, so the information about the amount of sediments was obtained from the sharpness of ADCh autocorrelation function [1, 2, 3].

ADCh is usually obtained slowly changing the wave frequency. This process can also be imagined in the following way (it is realized so in the nowadays equipment): the harmonic exciting signal of certain frequency is switched on, it is waiting for the received signal amplitude to become the stationary value, then it is stored, and after that a harmonic of a bit changed frequency signal is switched on, and again waiting for the stationary value, etc. This is equivalent to the exciting by the long burst. The signal amplitude of every burst signal is at first formed by a superposition of waves more times having spun the pipe, i.e., it is the complicated function *U(f, t)* of the frequency *f* and time *t*. This process was investigated in a broader frequency range [4]. Analyzing ADCh, essentially the small part of information carried by the function *U(f, t)* is used: one isoline *U(f, const)*, where *const* is of enough big value of time. So, it takes a lot of time to obtain all ADCh. An other drawback of this method is that the reflection from pipe unhomogeneounity deforms ADCh. It is expedient to investigate informativeness of *U(f,t)* beginning with the first received wave.

The object and the method of investigation

The received signal envelope *U(f, t)* when the zero order antisymmetric Lamb waves were excited at one side of a resonator (steel pipe of 150 mm diameter) and received on the opposite side, are investigated in the experiments. Both piezoceramic longitudinal waves transducers are 20 mm of diameter and were attached to the pipe through the liquid layer. Their contact area is near to the band and less than wavelength. So the transducers can be stated as point-type. The walls of the pipe are 8 mm of thickness; it is empty or with the layer of a burnt. The envelope *U(f,t)* of the received burst in the case of 10 mm layer is shown in Fig. 1. It was obtained exciting the transmitter by a enough long burst with the frequency discretely changed every 1 kHz; every isoline *U(const,t)* was stored at the rate of $333{\bullet}10^3$ samples/s and 256 samples were saved. After that the noise was reduced at every isoline with a 7-point moving average (smoothing). So *U(f, t)* is saved as an array 32x256. The isolines *U(f, const),* shown in Fig. 1, correspond to arch 8 point (in the series axis S1-S32), i.e., every 24 µs.

Resonance peaks forming every 7 kHz can be noted in the function *U(f, t).* They are the superposition of the first received and *n* times turned round the pipe waves with the phase difference $2n\pi$. So, it must be expected for the analysis of spectral function *U*(*f, t*) to be informative.

Two dimensional Fourier analysis of the function *U(f,t)* was performed with free distributed software [5]. This software gives the result in an array of 32x512, where the information about the amplitude of spectral components have the elements *a*(0, 0) – *a*(16, 28); *a*(0, 0) is the average of *U(f, t)*. The elements of the Fourier image *a*(0, 0) – *a*(13, 16) are depicted in Fig. 2. The quantity l/*f* with the time dimension showing the number of periodic function *U(f, t)* changes in unitary filling frequency interval is set on *x* axis. The quantity l/*t* showing the frequency of *U* changes in time is set on series axis (on *y* axis). It can be seen that the latter parameter is not informative.

The Fourier element steps Δ(l/*f*) and Δ(l/*t*) can be found from their connection to the inclusive original intervals *F* and *T*:

$$\Delta(1/f)=1/F \quad \text{and} \quad 1/(1/t)=1/T. \qquad (1)$$

Because *F* = 32 kHz and *T* = 0.768 ms, so it is obtained that Δ(l/*f*) = 0.03125 l/kHz and Δ(l/*t*) = 1.302 l/ms.

The maximums are seen on the isoline *a*(0, 0) – *a*(0.16) beside the elements 5, 10, 13 of the quantity l/*f* . The first of them matches the interference of the waves that came in the shortest way and spun one time the pipe; the other two correspond to the contribution of the waves with two and three rotations around of the pipe. The maximums match the filling frequency intervals about 7, 3.5, and 2.6 kHz, what is seen in Fig. 1.

Oscillations of the function *U(f, t*) are most clearly seen in the empty pipe and decreases when the layer of sediment increases [4]. So, the Fourier image can be the source of the information about the sediment layer.

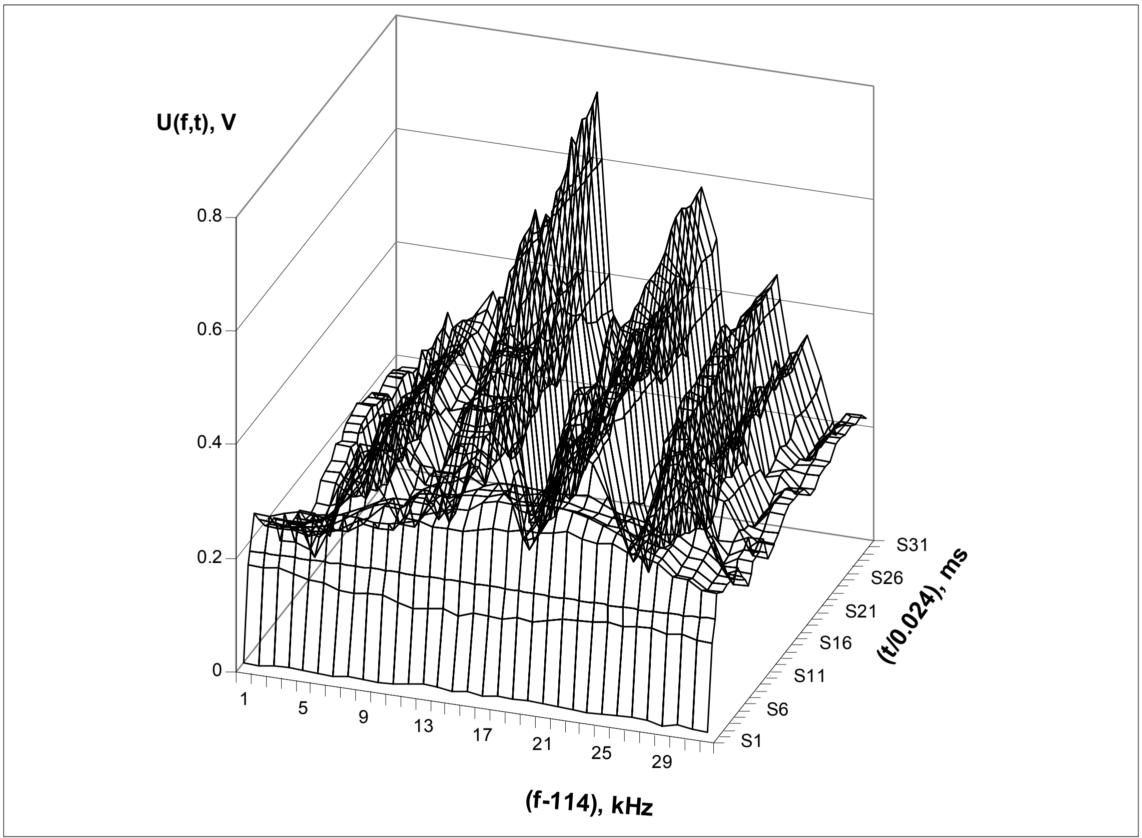


Fig. 1. **Received burst envelope *U(f, t)* in the steel pipe of 150mm diameter with the wall of 8 mm, when the carbon burnt layer is of 10mm**

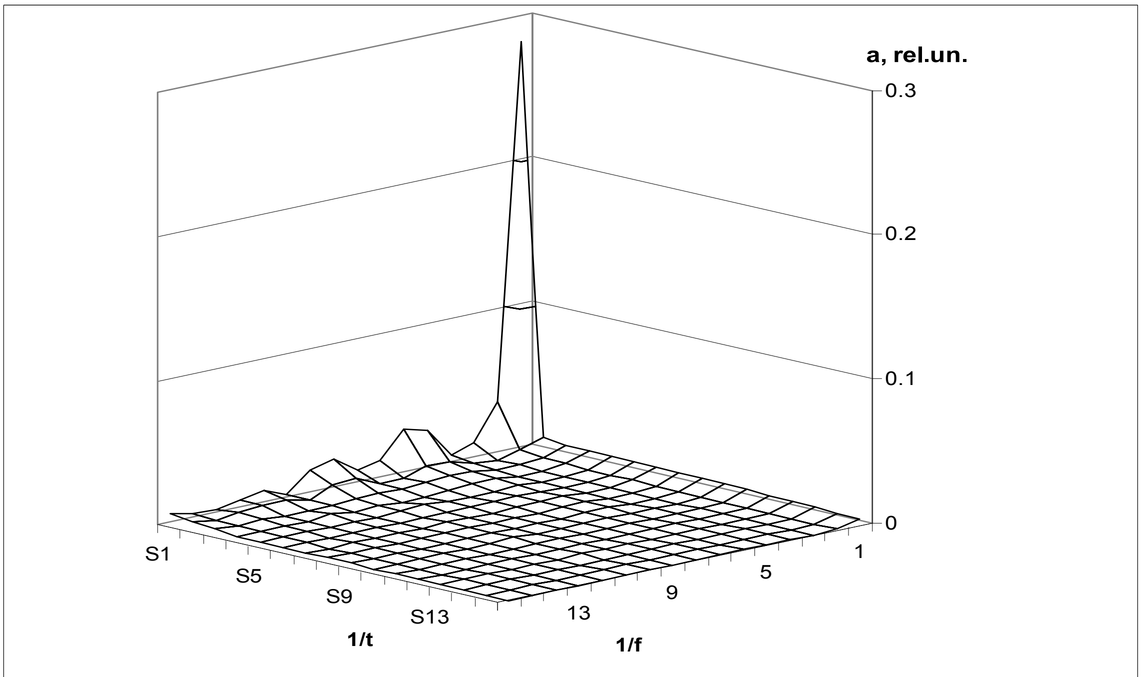


Fig. 2. **The part of Fourier image of the function *U(f, t)* (Fig. 1). The steps on the axis *Δ*(l/*f*) = 0.03125 l/kHz and *Δ*(l/*t*) = 1.302l/ms**

Optimal interval of the function *U(f, t)*

The amplitude of the waves that spun many times the circular resonator decreases because of two reasons:

- wave attenuation according to the law

$$U = U_0 \exp(-\alpha l), \quad (2)$$

where α is the attenuation coefficient, l is the wave path, U_0 is the amplitude in the radiation point,

- wave scattering

$$U = U_0 / l^{0,5}. \quad (3)$$

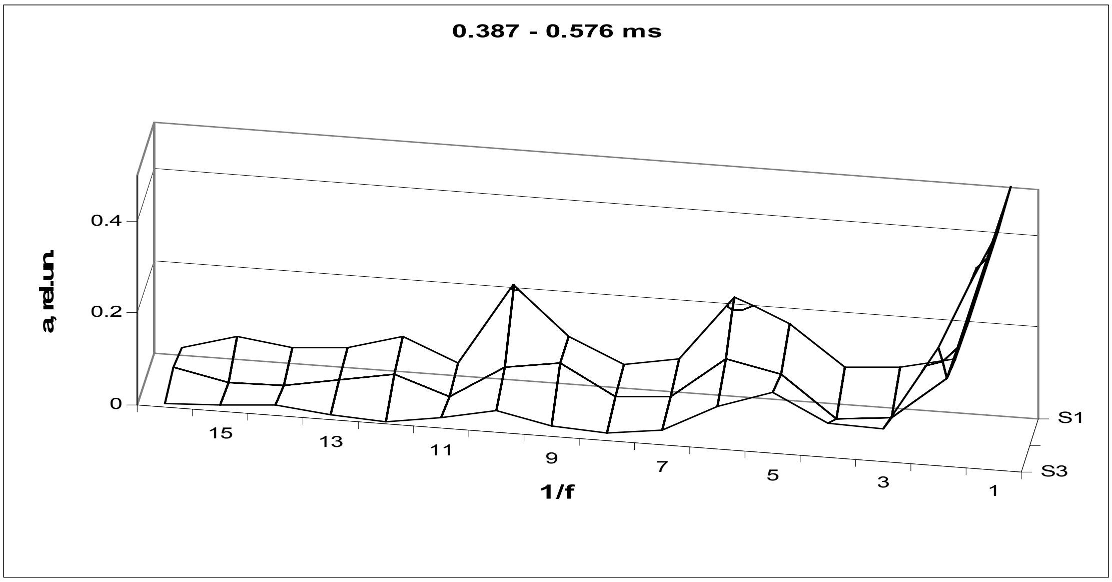


Fig. 3. **The elements of Fourier image *a*(0, 0) – *a*(0.16) of the arrays 32x64 of the function *U(f, t)* for two different position in time. S1 is the empty pipe; S2 and S3 are respectively with 10 and 20 mm of sediments. Step Δ(l/*f*) = 0.03125 l/kHz**

The first reason depends on the thickness of the layer. The frequency was changed in the interval of 115-146 kHz by 1 kHz steps; the amplitude of the received signal was stored every. The further waves are relatively weaker because of the scattering, so the distinguished interference is likely only for the first waves. For verification of this hypothesis the 2D-FFT transformation of the functions *U(f, t)* arrays of 32x64, shifted along *t* axis and obtained in the empty pipe with 10 and 20 mm of the burnt was performed.

The zero of the time is the arrival of a direct wave; then the wave with one rotation comes after 0.16 ms, the second and the third are respectively after 0.32 and 0.48 ms.

The biggest dependence of the *a*-maximums of image on sediment thickness must be expected according to Fig. 1 for the arrays that involve the arrival of the waves with 1 – 3 rotations (Fig. 1).

The hypothesis is proved by the elements *a*(0, 0) – *a*(0.16), normalized with respect to *a*(0, 0), in all three cases (empty pipe, and 10 and 20 mm of sediments) and the results are shown in Fig. 3. The position of original arrays in time is shown there also. To evaluate the waves that came further is not worth because of two reasons: their amplitude according to Eq.4 is small and the filling frequency step number must be increased decreasing them. Such a choice of the optimal function *U(f, t)* interval allows to increase the speed of the method.

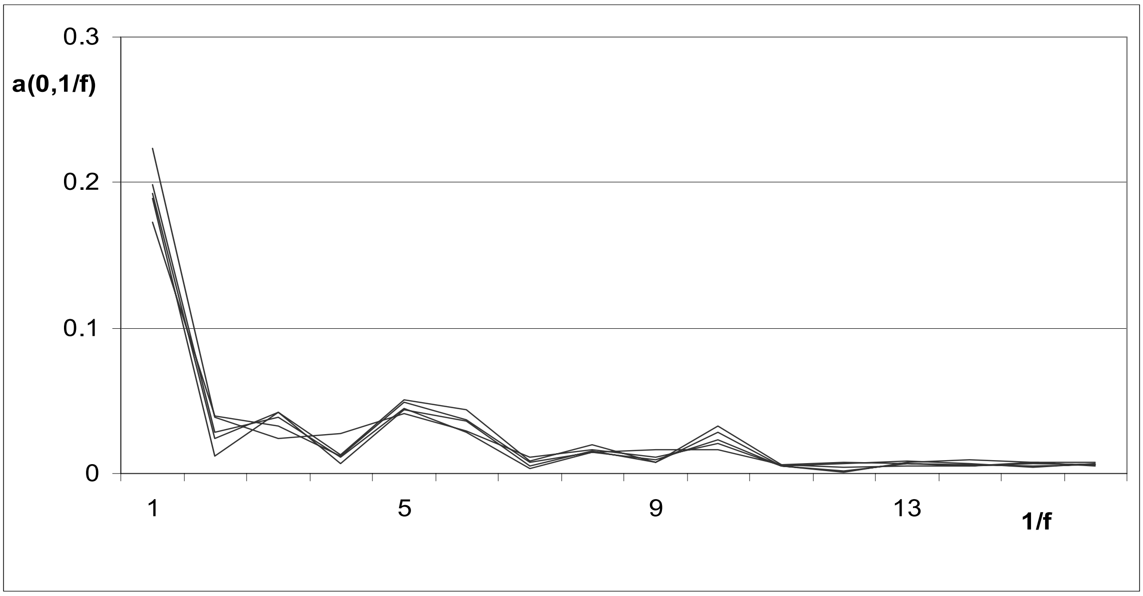
The recurrence of the results

In practice the outer surface of the pipe under investigation can be corroded or otherwise mechanically damaged. Every time by pressing the transducers to the pipe the spot of different square and shape of contact liquid is obtained. The strain of transducers, their frequency responses, and the character of the function *U(f, t)* changes at the same time. In order to check the influence of this factor the *U(f, t)* was stored five times having set the transducers in different places in the some cross-section of the pipe without sediments and with the sediment layer of 20 mm, but approximately face to face. The corrosion in the place of the transducer was cleaned in one case of five. The filling frequency was 10 μs to 810 μs (array 32x82). The time was accounted from the beginning of the irradiated burst. The excitation voltage was chosen so that *U(f, t)* maximum would be equal to 1 V. The 2D-FFT was performed for *U*(18,1) - *U*(81,32) elements. The Fourier image elements *a*(0,0) – *a*(0,16) of all cases are shown in Fig. 4 a and b.

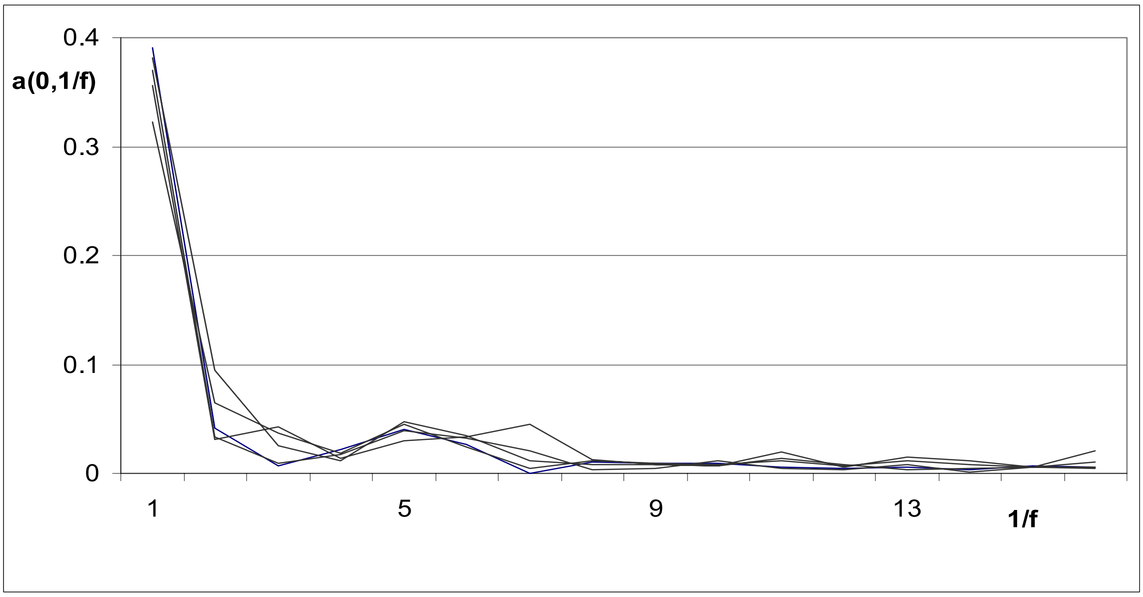
It can be seen (Fig. 4) that elements *a*(0,5) showing interference between directly coming and one time rotating waves coincides enough well. A bit worse coincidence is of *a*(0,10) elements. The sediment maximum of 20 mm near this element is scarcely seen. The images obtained with the transducers set in the places cleaned from corrosion mostly distinguishes in both cases.

The maximums near elements *a*(0,3) and *a*(0,8) are seen in Fig. 4a. The reason can be set from the appropriate origin *U(f, t)* shown in Fig. 5. The amplitude of resonance maximums (Fig. 5) decreases similarly as in Fig. 1 smoothly going to the edges of the filling frequency band, what can be explained by the frequency responses of the transducers. However, the decrease of amplitude maximum in the centre of this band is seen in Fig 5. One of the reasons is that the receiver can come into the environment of the knot when the transducers are set a bit asymmetric or the wave velocity distribution is asymmetric by appropriate frequency [6]. Spectral analysis allows avoiding the influence of this phenomenon.

Function *U(f, t)* depicted in Fig. 5 distinguishes with a bigger noise than in Fig. 1. One of the reasons is amplitude fixing using the digital storage oscilloscope TDS 2022 function “peak detect”. The maximal and minimal values of the signal are found in such mode in every time interval devoted to one sampling (in our case 10μs).



a



b

Fig. 4. **Elements of Fourier image a(0,0) – a(0,16) by fixing the transducers in the same cross-section five times: a) in empty pipe, b) – pipe with 20 mm of sediments. Step Δ(l/f) = 0.03125 l/kHz**

This interval was lose to the signal period, so in some cases one extreme meaning does not fit, but only close to it. The error of this phenomenon has the random character, but it has no influence to the Fourier image. So, *U*(*f, t*) was not filtrated.

Conclusions

The following conclusions can be done from the results of the experiment:

- the received burst amplitude as a function *U(f, t)* of time *t* and the filling frequency *f* gathers the information about wave attenuation and also about the thickness of the sediments in resonator (pipe);

- the mentioned information can be obtained having performed the 2D FFT transform of the function *U(f, t)* stored in the optimal time interval that involves the waves 1 – 3 times rotating the pipe;

- this method is less time expensive as the method of

ADCh autocorrelation function determination;

- the 2D FFT software is no problem (at least one-dimensional Fourier transform on the each array row and then one-dimensional transform on each column of intermediate array or vice versa);

- the recurrence of the results is not worse than using method of ADCh autocorrelation function determination.

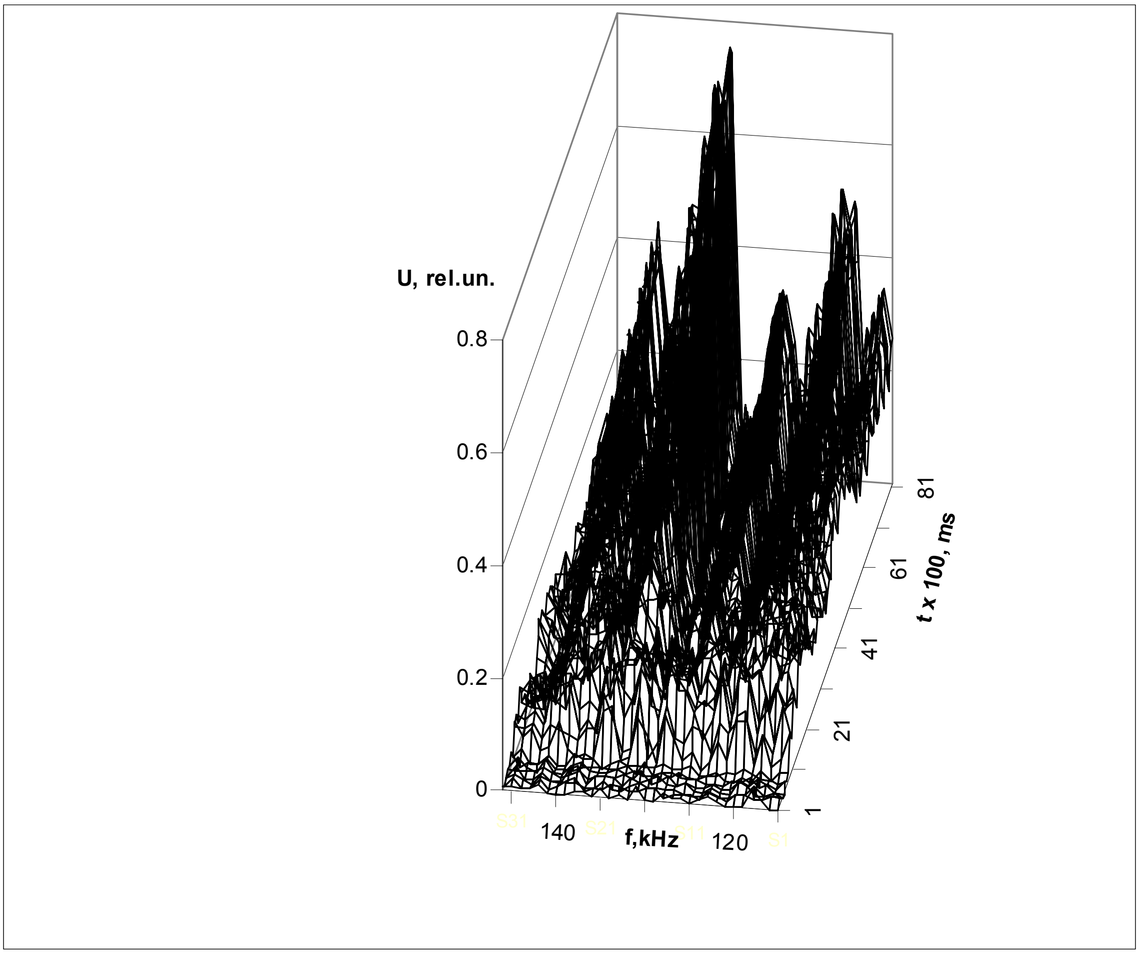


Fig. 5. **The example of *U(f, t)* function in the empty pipe**

Acknowledgement

The author thanks to German Academic Exchange Service (DAAD) for the given equipment pursuing the Equipment Grants Program for scholarship holders what allowed to perform this work.

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V. Sukackas

Signalo, priimto žadinant žiedinį rezonatorių radijo impulsais, informatyvumas

Reziumė

Nagrinėjama žiediniame rezonatoriuje–vamzdyje - priimto signalo gaubiamoji, kai siuntiklis žadinamas įvairaus dažnio radijo impulsais. Ji yra sudėtinga laiko ir užpildymo dažnio funkcija, turinti informacijos apie bangų slopinimą, kartu ir nuosėdų vamzdžio viduje kiekį. Pasiūlyta šią informaciją gauti atliekant dvimatę gaubiamosios Furjė transformaciją. Slopinimas ir nuosėdų kiekis atsispindi santykiniame Furjė atvaizdo ekstremumų dydyje. Pasiūlytas optimalus matavimų intervalas, apimantis pirmąsias 2 ar 3 apie vamzdį apibėgusias bangas. Tolimesnės bangos nenaudotinos dėl per mažos amplitudės.

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