

Effect of changing of the parameters of the cable network of monitoring systems of high-rise buildings on the basis of string converters on their operability

*Nikolay Gusev*¹, *Larisa Svatovskaya*², and *Alexandr Kucherenko*^{1,*}

¹Military Space Academy named after A.F. Mozhaysky, Zhdanovskaya st.13, St. Petersburg, 197198, Russia

²Emperor Alexander I St. Petersburg State Transport University (PGUPS), Moskovsky pr.9, St. Petersburg, 190031, Russia

Abstract. The article is devoted to the problem of improving the reliability of monitoring systems for the technical conditions of high-rise buildings. The improvement is based on string sensors with an impulsive excitation method ensuring the maximum signal-to-noise ratio at their output. The influence of the parameters of the monitoring system on the shape of the excitation impulses of the string, and, consequently, on the amplitude of the string vibration of the string converter is also considered in the article. It has been experimentally proved that the parameters of the excitation impulses of the string converters. The article presents the results of the experiments showing the effect of the fronts duration of the excitation impulses on the amplitude of the oscillations of the strings. The influence of the fronts duration of the excitation impulse with the frontal lengths up to 0.5 ms is studied at the excitation impulse duration not exceeding 0.5 times the duration of natural oscillation periods of the string. The experimental data are compared with the theoretical ones and hypotheses explaining their difference are advanced. The article suggests some methods of reducing the influence of the cable-switching equipment system parameters on the amplitude of string oscillations. The possibilities of improving the reliability of the systems developed on the basis of string sensors with an impulsive excitation method and used for monitoring the technical conditions of the high-rise buildings are proposed.

1 Introduction

In the practice of monitoring the stress-strain state of building structures and soil bases of buildings and construction throughout the whole period of their operation the long-term monitoring systems [1-3], and the systems for monitoring the state of high-rise buildings [4-10], have been widely applied.

* Corresponding author: kucher_90@bk.ru

In the terminology of the Ministry of Emergency Situations of the Ministry of Emergency Situations [11-13], such systems were called SMES (structured systems for monitoring and managing the engineering systems of buildings and structures). In hydraulic engineering such systems have received the name ASDC - automated systems of the diagnostic control [14-17].

ASDC and SMES systems, as a rule, are developed on the basis of the string converters. In addition to primary string converters, the SMES and ASDC systems include: switching and secondary equipment (specialized period-meters), as well as the cable network [17].

The method of measurement by using string converters is based on the dependence of the frequency ω (or period T) of the frequency resonator (string) oscillation on the string extension stress which in each particular string converter is proportional to the measured parameter P (linear displacement, pressure, temperature, etc.).

To excite the string vibrations of the string measuring transducers with impulse excitation (STMS) electromagnetic coils are used. When reeding an excitation impulse of a rectangular shape of standard amplitude and duration to the terminals, an excitation impulse with a certain amplitude F and duration τ_u is generated in the coil. The force impulse excites the damped oscillations of the string y by "pinch" that induce e , the frequency ω , or the period T in the electromagnetic coil e , which can be measured up to some preassigned value of the amplitude determined by interference level corresponding to the minimum value y_{min} string oscillation amplitude. The maximum value of the amplitude of the string oscillations y_{max} is limited by the design gap between the string in the unexcited state and the core of the electromagnetic coil of excitation δ . The value of the gap for commercially available STMS lies in the range $0.35 \div 0.50$ mm [17].

Each STMS has an individual calibration, as shown in **Fig. (1)**, produced with the excitation of string vibrations by standard rectangular impulses, their parameters being defined in control documents [17]. The stated parameters of the excitation impulses should provide the value of the amplitude of the damped oscillations of the string in the range from y_{max} to y_{min} for the entire measurement interval (t_{u3M}). These conditions ensure stable oscillation of the STMS strings and reliable operation of the SMES and ASDC systems.

From the theory of oscillations [18-22] it is known that when an oscillating system is acted upon by a impulse the duration of which is equal to or multiple the system oscillation period, there appears the probability that the system oscillations will not arise or will have a negligible amplitude. Comparative analysis of the excitation impulses duration (τ_u) of serially produced secondary equipment for STMS [23], the values of which lie in the range from 300 to 700 mks, with the duration of the oscillations periods of the STMS (T) strings in the operating range of the measured parameters, 400 to 2000 mks [23], showed that the range of durations τ_u by $25 \div 30\%$ overlaps the operating range of the values of the oscillation periods of the strings T , as shown in **Fig. (1)**.

This means that in the mentioned range of the oscillation period of the STMS string, the values of its amplitude and, consequently, the EMF excitation induced in the electromagnetic coil will fall, which will lead to the decrease in the "signal/noise" ratio at the output of the STMS and the instability of its operation.

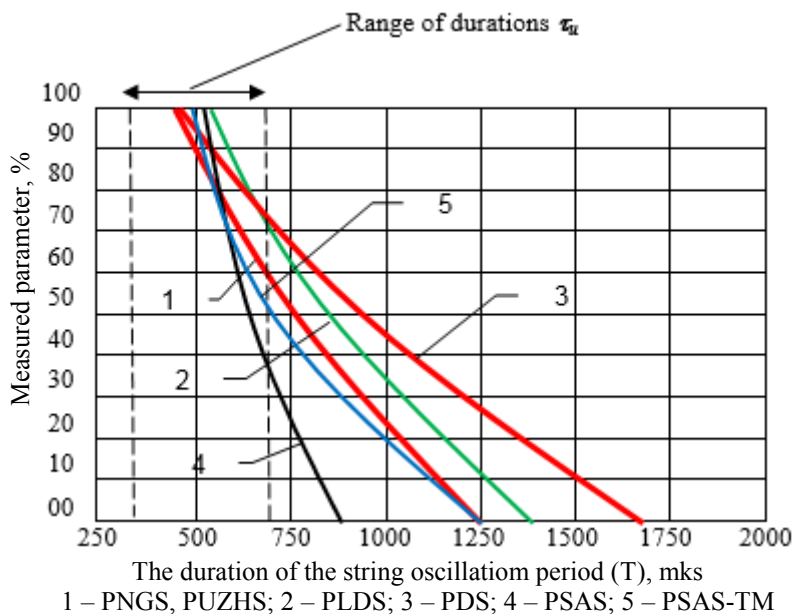


Fig. 1 Dependence of measured quantities on the period of string vibration for string converters with impulsed excitation of string vibrations.

The studies have shown [22] that the parameters of the vibration of the STMS string depend on the amplitude F and the duration of the excitation impulse of the string. The dependence of the string vibration amplitude on the duration of the excitation impulse for various types of STMS is presented in **Fig. (2)**.

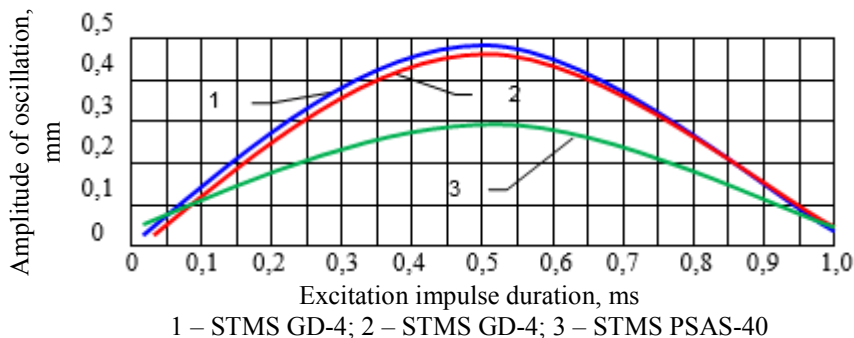


Fig. 2 Dependence of the vibration amplitude of the STMS string on the duration of the excitation impulse.

The invariance of the (standard) values of the parameters of the amplitude F and the duration τ_u of the string excitation impulse with a change in the frequency T of oscillations y of the string in the operating frequency range of the STMS results in the sharp decrease of the string oscillations amplitude. This defect was eliminated in subsequent developments of the secondary equipment with automatic correction of the parameters of the amplitude F and the duration τ_u of the string oscillations impulse as a function of the value of T [22].

Experience of the SMES exploitation showed that the string vibration amplitude of each specific standard sensor in the systems of the high-rise buildings monitoring, even when adjusting the parameters of the amplitude F and the duration τ_u of the excitation impulse, differed, and these differences tended to change with time.

The authors put forward the hypothesis that the excitation impulse parameters change while passing through communication cables and switching equipment.

When calibrating the STMS, the secondary equipment is connected directly to the transducer and of rectangular form is performed with a rectangular excitation calibration [24]. However, on real objects in the SMES or ASDC STMS systems, string converters are connected to the secondary equipment by means of cables, for example, CRHD 2x1.5 (TC 16.505.065-75) and switching equipment, as it is regulated in the normative and technical documentation for STMS. The cable CRHD 2x1.5 has a capacitance C (the capacitance of 1 m of cable is not more than 150 pF) and the electrical resistance of the conductors R (no more than 15 Om per 1 km of cable length). Consequently it is an integrating circuit. When passing through it a rectangular excitation impulse distorts its shape, which is expressed in the formation of the front and back fronts with a duration of τ_f , caused by the time constant of the chain $t = RC$. For normal operation conditions of the CRHD cable 2x1.5, the value of the chain time constant on the real objects does not exceed $0.1 \div 2.5$ mks, which is incommensurably small in comparison with the excitation impulse durations (from 300 to 700 mks) and does not significantly change the process of string oscillations excitation.

However, during operation, the normalized values of C and R of the cable and the contact resistance R_{nks} of the switching equipment change as a result of aging or external influences and can increase tens or even hundreds times, which results in the significant changes in the shape of the excitation impulse.

The main factors affecting the capacity of the cable are: electrical aging, oxidation, thermal aging and humidification. The investigations carried showed that, with a constant resistance of the cable veins, the formation of the excitation impulse fronts, with the duration τ_f , commensurable with the duration τ_u , takes place with the increase of the cable capacity CRHD 2x1.5 tens times, which is quite probable in practice under the influence of the actual parameters of the influencing factors.

The resistance of the cable line consists of the resistance of the cable cores and the contact resistance of the switching equipment of the SMES system.

The most significant contribution to the total resistance of the system "cable line – switching equipment" is made by the contact resistance of the commuting equipment, which can increase tens or even hundreds times during corrosion or oxidation of contacts of switching equipment. Thus, during the operation of the cable network and the switching equipment of the SMES systems, their parameters change within the limits that significantly affect the time constant of the circuit and the formation of the fronts of the excitation impulses that approximate its shape to the trapezoidal.

The purpose of this investigation was to state the regularities of the string vibration amplitude change of the string converters used in the systems for high-rise building monitoring. The change is caused by the distortion of the excitation impulse shape. The influence of the process on the efficiency of the monitoring systems has also been investigated.

2 Materials and methods

The amplitude y_n of the oscillation of the n 'th string harmonic excited by a trapezoidal impulse depends on the coefficient of the n 'th harmonic (ξ_n). The coefficient ξ_n depends on the duration of impulse excitation τ_u , the duration of its fronts τ_f , as well as the circular frequency of the n th harmonic ω_n , and has the form [22]:

$$\xi_n = \frac{2}{\omega_n \tau_f} \sin \frac{\omega_n \tau_f}{2} \sin \frac{\omega_n \tau_u}{2} \tag{1}$$

Fig. (3). shows the theoretical dependence of the amplitude y_1 of the first string harmonic vibration on τ_u and τ_f STMS (PLDS -150) at $T_l = 1.0$ ms.

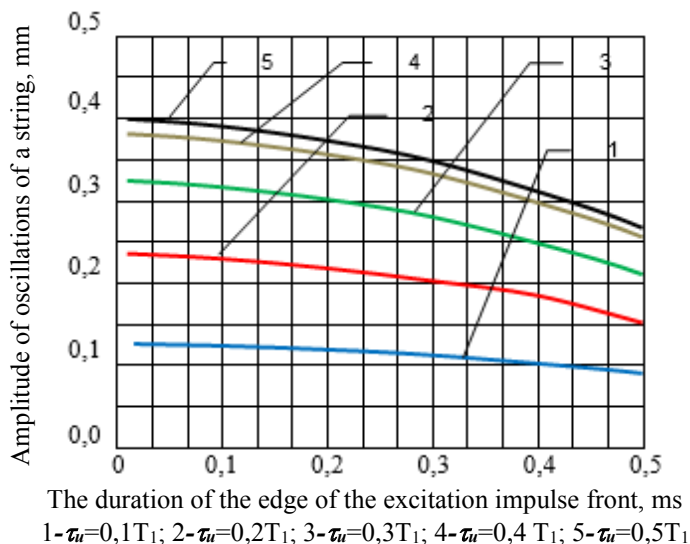


Fig. (3). – Dependence of the first harmonic amplitude ($n = 1$) of the string vibration on the duration of the excitation impulse front τ_f for the STMS (PLDS -150) for various values of τ_u at $T_l = 1.0$ ms.

The investigations were carried out by using standard sensors of the PLDS-150 type with the parameters specified in the standards [14, 17], and according to the standard procedure [23, 25]. The devices for recording static and dynamic displacements (DRSDFD) as the secondary equipment were used. They have the following main parameters:

The parameters of the request impulse (excitation) with a smooth adjustment:

- voltage 135 ÷ 165 V,
- durability 0,25 ÷ 1,00 ms,
- repetition period not less than 2 s.

Parameters of STMS (PLDS-150):

- constructive gap δ 0,4 mm
- output period range 450 ÷ 1250 mks

Experimental conditions:

- output cable such as CRHD 2x1,5
- ambient temperature +20°C
- recording equipment oscilloscope S1-96M

The experiment was carried out at five values of the impulse duration in excitation τ_u in the range from $0.1 T_l$ to $0.5 T_l$ in steps of $0.1 T_l$ and with a front duration change τ_f in the range from 0.0 to $0.5 T_l$ in steps of $0.1 T_l$ at $T_l = 1.0$ ms. The amplitude of the excitation impulse ensured the maximum value of the string vibration amplitude $y_{max} \leq \delta$ at a value of $T_l = 1.0$ ms at an impulse voltage of 145.5 V.

The shape of the excitation impulse obtained during the experiment is shown in **Fig. 4**

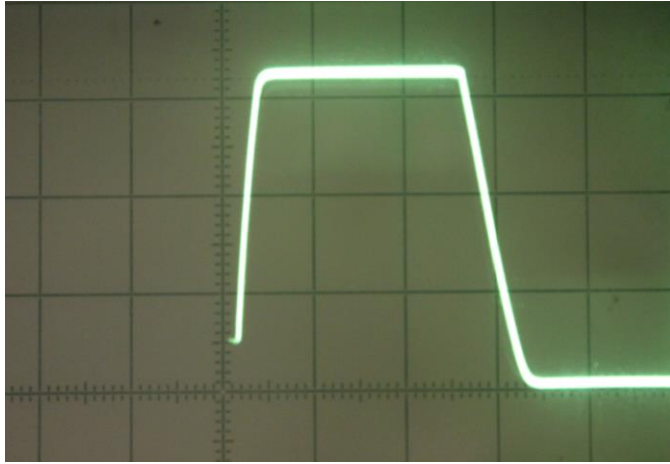


Fig. 4 The shape of the excitation impulse at $\tau_u = 0,5T_l$ and $\tau_f = 0,1T_l$.

3 Results

The results of the experiment are presented on **Fig. 5**

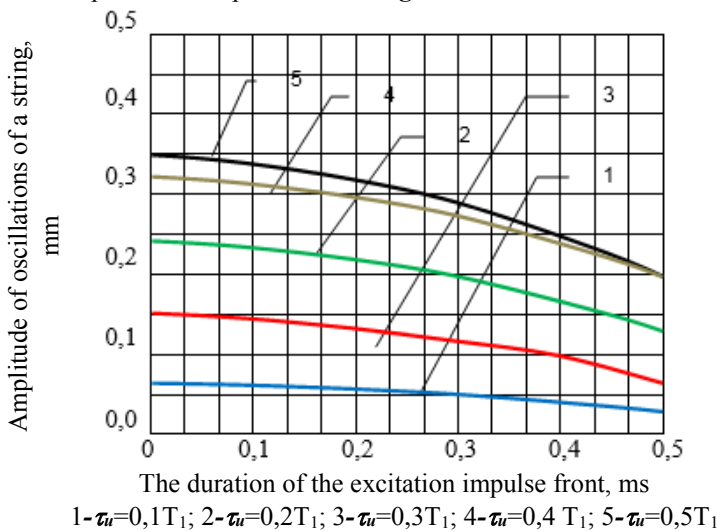


Fig. 5 Experimental dependences of the amplitude of the first harmonic ($n=1$) of the string vibration on the duration of the excitation impulse front τ_f for STMS (PLDS-150) at various values of τ_u .

The materials presented in **Fig. 5** show that:

- 1) The amplitude of the oscillations of the string has a nonlinear dependence on the duration of the excitation impulse front τ_u and its fronts duration τ_f .
- 2) As the duration of the excitation impulse front increases, the amplitude of the vibration of the string y decreases. So for $\tau_f < 0,5T_l$, i.e. at the maximum amplitude of the excitation impulse and the preservation of its trapezoidal form, the string oscillation amplitude drops by 45-50%.

4 Discussion

The experimental data of the dependence of the amplitude of the string vibrations on the duration of the fronts of the excitation impulse τ_f , presented in **Fig. (5)**, differ from the theoretical ones presented in **Fig. (3)**. Thus, the values of the amplitude of the string vibrations obtained in the course of the experiment are lower than the theoretical values presented in **Fig. (3)**, up to 26% at $\tau_u = 0.5$ and $\tau_f = 0.5T_l$ and up to 45% at $\tau_u = 0.2T_l$ and $\tau_f = 0.5T_l$.

This phenomenon is obviously due to at least three circumstances:

1) The theoretical dependence (1) was obtained for the case of equality of the values of the front and back fronts, i.e. symmetric shape of the excitation impulse. The actual shape of the excitation impulse during the experiment was different from the symmetric one, as shown in **Fig. (4)**, namely, the leading front is 25-35% shorter than the trailing edge.

2) Oscillation amplitude of only the first harmonic y_1 without taking into account highest harmonics ($n>1$) was fixed while the energy of the excitation impulse was distributed between them.

3) During the experiment, it was not possible to fix the effect of the string oscillation precession, in the presence of which the oscillations amplitude will always be lower than the oscillations in one plane.

The experiment confirmed the general tendency of the string oscillation amplitude decrease when the duration of the excitation impulse front increases in the range up to $\tau_p < 0.5T_l$. The decrease of the string vibration amplitude and, consequently, of the excitation of the EMF e induced in the electromagnetic coil results in the decrease of the "signal/noise" ratio at the output of the STMS and the instability of the whole monitoring system.

5 Conclusions

During the experimental investigations it was proved that in order to maintain the maximum amplitude of the string oscillations y_{\max} (provision the maximum "signal/noise" ratio) over the entire measurement interval (t_{zm}), the amplitude of the excitation impulse of the STMS strings must be corrected in proportion to the duration of the excitation impulse fronts τ_f , i.e. to the change of the parameters C and R of the «cable-switching equipment» system. These conditions ensure the stable oscillation of the SIPI strings and reliable operation of the STMS systems built on their basis. If these conditions are not fulfilled, STMS begins to give unstable readings soon after the introduction of the SMES systems into operation (from 1 to 5 years). So, they are excluded from the measurements as coming out of service and the informative basis for making decisions on the technical state of the high-rise buildings is reduced.

The experimental results obtained allow us to formulate future directions of the research:

- investigation of the influence of different durations of the front and back fronts of excitation impulses on the string oscillations amplitude;
- investigation of the influence of the precession of the string oscillation and the highest harmonics on the string oscillations amplitude;
- investigation of the ways of reducing the values of the parameters C and R of the «cable-switching equipment» system or their changes in time.

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