EVALUATION OF THE PERIOD OF SENSORS MOTION PARAMETERS OF THE TRAIN

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Contribution to the state of the art
DOI: **10.7251/JIT1801014B** UDC: **629.4.05:519.63**

Abstract: The choice of polling period sensors for measuring the speed and acceleration of the train can be produced using the spectral representation of functions of velocity and acceleration from time to time. Using the spectral method of determining the period of the survey, you can choose different value depending on the category of the train and its dynamic characteristics. For high-speed trains, the period of sensors is less than for trucks, since the latter are tightened by the transients during acceleration and deceleration.

Keywords: Hartley transform, parameters of the train, period of sensors, spectral method.

INTRODUCTION

The study of the spectral composition of the considered classes of functions will be made using the Hartley transform. R. Hartley introduced a couple of integral transforms in an article published in the journal *Proceedings of the Institute of Radio Engineers* in 1942. If you use frequency f instead of angular frequency ω, it is as follows:

$$H(f) = \int_{-\infty}^{+\infty} V(t) cas 2\pi f t dt,$$
$$V(t) = \int_{-\infty}^{+\infty} H(f) cas 2\pi f t dt. \tag{1}$$

Then $H(f)$ is regarded as the Hartley transform of the function $V(t)$, which in turn is the inverse Hartley transform of the function $H(f)$. Function $cast \equiv \cos t + \sin t$. Any function can be represented uniquely as a sum of even and odd component. For instance, $H(f) = E(f) + O(f)$, where $E(f)$ and $O(f)$ are respectively the even and odd components of the function $H(f)$.

Then:

$$E(f) = \int_{-\infty}^{+\infty} V(t) \cos 2\pi f t dt,$$
$$O(f) = \int_{-\infty}^{+\infty} V(t) \sin 2\pi f t dt. \tag{2}$$

These two integrals are known as, respectively, the cosine - and sine-Fourier transform, which have tabulated values [1].

REPRESENTATION OF REAL FLUCTUATIONS

Energy and phase spectra can be obtained directly from the Hartley transform.Thus we have the energy spectrum:

$$P(f) = E^2(f) + O^2(f) = \frac{[H(f)]^2 + [H(-f)]^2}{2}, \tag{3}$$

and the phase spectrum:

$$\arg F(f) = arctg \frac{-O(f)}{E(f)} = \frac{H(-f) - H(f)}{H(f) + H(-f)}. \tag{4}$$

In a sense, the Hartley transform can be considered as a smooth form of representation of real fluctuations. Being purely physical, the Hartley transform does not require other ways of representing [2]. We will use the following hypothesis on the speed of the train:

$$V(t)=\begin{cases}V_0+at, 0\le t<T\\ V, T\le t<T_1\\ V-at, T_1\le t<T_2\\ 0, t<0, t\ge T_2\end{cases}. \quad (5)$$

Then the even part of the Hartley transform is defined determined as follows:

$$E_v(f)=\int_0^T (V_0+at)\cos 2\pi ftdt+\int_T^{T_1} V\cos 2\pi ftdt+\int_{T_1}^{T_2}(V-at)\cos 2\pi ftdt. \quad (6)$$

Using tabulated values of the integrals [3]:

$$\begin{aligned}&\int \cos(a+bx)dx=\frac{1}{b}\sin(a+bx)\\ &\int x\cos x dx=\cos x+x\sin x\end{aligned}, \quad (7)$$

we get:

$$\begin{aligned}E_v(f)&=\frac{1}{2\pi f}[V_0\sin 2\pi fT+V\sin 2\pi fT_2-V\sin 2\pi fT]+\\ &+\frac{a}{4\pi^2 f^2}[\cos 2\pi fT+2\pi fT\sin 2\pi fT-1-\cos 2\pi fT_2-\\ &-2\pi fT_2\sin 2\pi fT_2+\cos 2\pi fT_1+2\pi fT_1\sin 2\pi fT_1].\end{aligned} \quad (8)$$

The odd part of the Hartley transform is defined by the following expression:

$$O_v(f)=\int_0^T (V_0+at)\sin 2\pi ftdt+\int_T^{T_1} V\sin 2\pi ftdt+\int_{T_1}^{T_2}(V-at)\sin 2\pi ftdt. \quad (9)$$

Using tabulated values of the integrals [3]:

$$\begin{aligned}&\int \sin(a+bx)dx=-\frac{1}{b}\cos(a+bx),\\ &\int x\sin x=\sin x-x\cos x,\end{aligned} \quad (10)$$

we get:

$$\begin{aligned}O_v(f)&=-\frac{V_0}{2\pi f}(\cos 2\pi fT-1)+\frac{V}{2\pi f}(\cos 2\pi fT-\cos 2\pi fT_2)+\\ &+\frac{a}{4\pi^2 f^2}(\sin 2\pi fT-2\pi fT\cos 2\pi fT-2\pi fT-\sin 2\pi fT_2+\\ &+2\pi fT_2\cos 2\pi fT_2+\sin 2\pi fT_1-2\pi fT_1\cos 2\pi fT_1).\end{aligned} \quad (11)$$

The model of acceleration change in train movement will be considered in the following form:

$$A(t)=\begin{cases}0, t<0\\ a(1-e^{-\frac{t}{\tau}}), 0\le t<T\\ ae^{-\frac{(t-T)}{\tau}}, T\le t<T_1\\ -a(1-e^{-\frac{(t-T_1)}{\tau}}), T_1\le t<T_2\\ -ae^{-\frac{(t-T_2)}{\tau}}, t\ge T_2\end{cases} \quad (12)$$

Even part of the Hartley transform for this case is described by the expression:

$$\begin{aligned}E_a(t)&=\int_0^T a(1-e^{-\frac{t}{\tau}})\cos 2\pi ftdt+\int_T^{T_1} ae^{-\frac{(t-T)}{\tau}}\cos 2\pi ftdt+\\ &+\int_{T_1}^{T_2}-a(1-e^{-\frac{(t-T_1)}{\tau}})\cos 2\pi ftdt+\int_{T_2}^{\infty}-ae^{-\frac{(t-T_2)}{\tau}}\cos 2\pi ftdt.\end{aligned} \quad (13)$$

Using tabular values of the integral [3]:

$$\int e^{bx}\cos nx dx=\frac{e^{bx}}{b^2+n^2}(b\cos nx+n\sin nx), \quad (14)$$

given that if $T>4{,}6\tau$ can be considered a $e^{-\frac{T}{\tau}}\approx 0$:

$$\begin{aligned}E_a(t)&=\frac{a}{\tau(\frac{1}{\tau^2}+4\pi^2 f^2)}+\frac{a}{2\pi f}(\sin 2\pi fT+\sin 2\pi fT_1+\sin 2\pi fT_2)+\\ &+\frac{a}{(\frac{1}{\tau^2}+4\pi^2 f^2)}[(\frac{1}{\tau}\cos 2\pi fT-2\pi f\sin 2\pi fT)+\\ &+(\frac{1}{\tau}\cos 2\pi fT_1-2\pi f\sin 2\pi fT_1)-(\frac{1}{\tau}\cos 2\pi fT_2-2\pi f\sin 2\pi fT_2)].\end{aligned} \quad (15)$$

The odd component is the sum of the following integrals:

$$\begin{aligned}O_a(t)&=\int_0^T a(1-e^{-\frac{t}{\tau}})\sin 2\pi ftdt+\int_T^{T_1} ae^{-\frac{(t-T)}{\tau}}\sin 2\pi ftdt+\\ &+\int_{T_1}^{T_2}-a(1-e^{-\frac{(t-T_1)}{\tau}})\sin 2\pi ftdt+\int_{T_2}^{\infty}-ae^{-\frac{(t-T_2)}{\tau}}\sin 2\pi ftdt.\end{aligned} \quad (16)$$

Using tabular values of the integral [3]:

$$\int e^{bx}\sin nx dx=\frac{e^{bx}}{b^2+n^2}(b\sin nx-n\cos nx), \quad (17)$$

we get:

$$O_a(t) = \frac{a}{2\pi f}(1 - \cos 2\pi fT + \cos 2\pi fT_2 - \cos 2\pi fT_1) +$$
$$+ \frac{a}{(\frac{1}{\tau^2} + 4\pi^2 f^2)}[(\frac{1}{\tau}\sin 2\pi fT + 2\pi f \cos 2\pi fT) + \tag{18}$$
$$+ (\frac{1}{\tau}\sin 2\pi fT_1 + 2\pi f \cos 2\pi fT_1) - (\frac{1}{\tau}\sin 2\pi fT_2 + 2\pi f \cos 2\pi fT_2)].$$

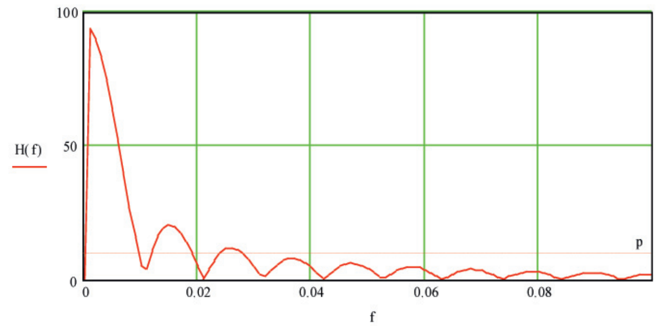

Fig. 1. *The energy spectrum function of velocity (trapezoidal model, T1=5 s, T2=95 s, T=100 sec)*

In microprocessor system of interval traffic control, rating speed of the train and its acceleration is produced digitally through certain discrete intervals.

Discretization of measurement signals leads to a methodological error, which can be determined from the conditions that limit the spectrum of the signal of interest [1] in accordance with the theorem by Rayleigh

$$s_{ou} = \sqrt{\frac{1}{\pi}(\int_{\omega_B}^{\infty} P(\omega)d\omega)}\,. \tag{19}$$

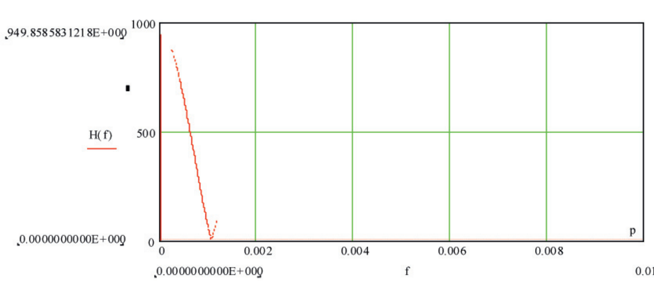

Fig. 2. *The energy spectrum function of velocity (trapezoidal model T1=50 sec, T2=950 h, T=1000 sec)*

However, this formula is not convenient for numerical integration, so given that $s_{ou}^2 = s^2 - s_{oc}^2$, we have the expression for the relative error of discretization:

$$\frac{s_{ou}}{s} = \sqrt{(1 - \frac{s_{oc}^2}{s^2})} = \sqrt{1 - \frac{\int_0^{\omega_B} P(f)df}{\int_0^{\infty} P(f)df}}, \tag{20}$$

where $\omega_B = \frac{2\pi}{t_B}$ is the maximum value of the angular frequency determined by the sampling time reports for discretization of t_B, $P(f)$ represents the energy spectrum, calculated according to the expression (3).

Conclusion

Method of evaluation period of sensors measuring the acceleration and speed of the train is as follows. A relative sampling error is specified and, according to expression (20), the upper limit of the angular frequency is determined, at which a predetermined error is provided. It is uniquely determined by the polling period of t_B sensors. Using the spectral method of determining the period of the survey, you can choose different t_B value depending on the category of the train and its dynamic characteristics. For high-speed trains, the period of sensors is less than for trucks, since the latter are tightened by the transients during acceleration and deceleration (parameters T_1 and T_2 in the expression (5)).

A graph of the relative error from the sampling period of sensors is shown in Fig. 3 and Fig. 4.

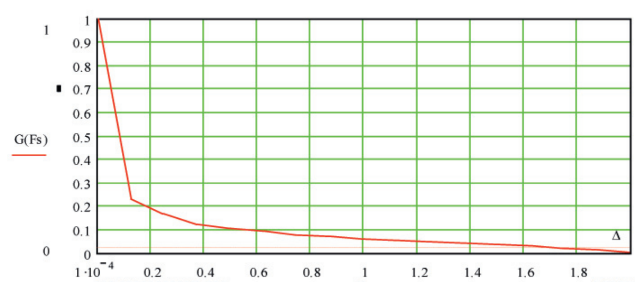

Fig. 3. *The dependence of relative sampling error from the sampling frequency of the speed sensor (trapezoidal model of motion, T1=5 s, T2= 95 s, T=100 sec)*

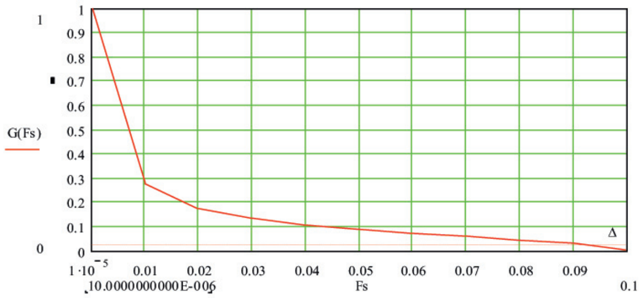

Fig. 4. *The dependence of relative sampling error from the sampling frequency of the speed sensor (trapezoidal model of motion T1=50 sec, T2=950 h, T=1000 sec)*

In this case the sampling time is determined with an error which is less than 2.5%.

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Submitted: March 28, 2018
Accepted: June 2, 2018

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For citation

Bestemyanov Petr Filimonovich, Evaluation of the period of sensors motion parameters of the train , *JITA – Journal of Information Technology and Applications*, PanEuropien University APEIRON, Banja Luka, Republika Srpska, Bosna i Hercegovina, JITA 8(2018) 1:14-17, (UDC: 629.4.05:519.63), (DOI: 10.7251/ JIT1801014B), Volume 8, Number 1, Banja Luka, june 2018 (1-44), ISSN 2232-9625 (print), ISSN 2233-0194 (online), UDC 004