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A SIMPLE, VIRTUAL PHASE SHIFT METER

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Abstract – Phase shift measurements are nowadays typically made in programmed measurement systems. Many of them are realized as virtual instruments, so called VI's. There are many algorithmic methods of phase shift measurements described in the literature, but sometimes these methods are complicated. In this paper an idea of a simple method of phase shift measurement has been presented. The method uses derivatives of measurement signals and inverse trigonometric functions. A simple function allows calculating of the measured phase shift. The method has been implemented as a virtual instrument using the LabVIEW packet. The implementation is very simple and the virtual instrument can become a part of a more complicated measurement instrument. The inaccuracy of the phase shift measurement is maximal 3 deg. It is not very accurate instrument, but in some applications the accuracy can be accepted.

Keywords: phase shift measurements, virtual instruments

1. INTRODUCTION

There is a plenty of phase shift measurement methods described in literature [1...9]. Typically, they are algorithmic methods which use programmatically signal processing. In the main group there are methods, which use discrete integral transformations, for example the fast Fourier transform FFT or the Wigner transform. Some methods use an adaptive sampling, other use statistic methods, for example a calculation of correlation and autocorrelation coefficients. Some of the methods are suitable for measuring the phase shift changing in time. Other methods can be applied only for a static phase shift.

2. MEASUREMENT ALGORITHM

Two sinusoidal signals $a(t)$ and $b(t)$ are described by equations:

$$\begin{cases} a(t) = A_m \sin(\omega t) \\ b(t) = B_m \sin(\omega t + \varphi) \end{cases}, \tag{1}$$

where A_m is the amplitude of the signal $a(t)$; B_m is the amplitude of the signal $b(t)$; φ is measured constant phase shift between the signals $a(t)$ and $b(t)$; ω is an angular frequency of $a(t)$ and $b(t)$ signals.

Let's differentiate the signals $a(t)$ and $b(t)$ in the time domain:

$$\begin{cases} \frac{\mathrm{d}}{\mathrm{d}t} a(t) = \omega A_m \cos(\omega t) \\ \frac{\mathrm{d}}{\mathrm{d}t} b(t) = \omega B_m \cos(\omega t + \varphi) \end{cases}. \tag{2}$$

We can calculate the relation between the signal and its derivative in a t_p moment for $\sin \omega t_p \neq 0$:

$$\frac{\frac{\mathrm{d}}{\mathrm{d}t} a(t_p)}{\omega a(t_p)} = \frac{\omega A_m \cos(\omega t_p)}{\omega A_m \sin(\omega t_p)} = \frac{1}{\tan(\omega t_p)} \tag{3}$$

or the following relation for $\cos \omega t_p \neq 0$:

$$\frac{\omega a(t_p)}{\frac{\mathrm{d}}{\mathrm{d}t} a(t_p)} = \frac{\omega A_m \sin(\omega t_p)}{\omega A_m \cos(\omega t_p)} = \tan(\omega t_p). \tag{4}$$

We can also calculate similar relations for the $b(t)$ signal for $\sin(\omega t_p + \varphi) \neq 0$:

$$\frac{\frac{\mathrm{d}}{\mathrm{d}t} b(t_p)}{\omega b(t_p)} = \frac{\omega B_m \cos(\omega t_p + \varphi)}{\omega B_m \sin(\omega t_p + \varphi)} = \cot(\omega t_p + \varphi), \tag{5}$$

or the relation for $\cos \omega t_p \neq 0$:

$$\frac{\omega b(t_p)}{\frac{\mathrm{d}}{\mathrm{d}t} b(t_p)} = \frac{\omega B_m \sin(\omega t_p + \varphi)}{\omega B_m \cos(\omega t_p + \varphi)} = \tan(\omega t_p + \varphi). \tag{6}$$

The equations (5) and (6) describe trigonometric functions of phases of the signals $a(t)$ and $b(t)$, so using inverse trigonometric functions we can calculate phases of both $a(t)$ and $b(t)$ signals. For $a(t)$ phase of the signal can be calculated as

$$\psi_1 = \operatorname{arccot} \frac{\frac{\mathrm{d}}{\mathrm{d}t} a(t_p)}{\omega a(t_p)} \tag{7}$$

or

$$\psi_1 = \arctan \frac{\omega a(t_p)}{\frac{\mathrm{d}}{\mathrm{d}t} a(t_p)} . \tag{8}$$

Similarly the phase of the signal $a(t)$ can be calculated:

$$\psi_2 = \operatorname{arccot} \frac{\frac{\mathrm{d}}{\mathrm{d}t} b(t_p)}{\omega b(t_p)} \tag{9}$$

or

$$\psi_2 = \arctan \frac{\omega b(t_p)}{\frac{\mathrm{d}}{\mathrm{d}t} b(t_p)} . \tag{10}$$

Functions ψ_1 and ψ_2 don't depend on amplitudes of both signals.

If $b(t_p)\neq 0$ and $a(t_p)\neq 0$ then the phase shift φ can be calculated as a difference of phases ψ_2 and ψ_1:

$$\varphi = \psi_1 - \psi_2 = \operatorname{arccot} \frac{\frac{\mathrm{d}}{\mathrm{d}t} b(t_p)}{\omega b(t_p)} - \operatorname{arccot} \frac{\frac{\mathrm{d}}{\mathrm{d}t} a(t_p)}{\omega a(t_p)} , \tag{11}$$

or if $\frac{\mathrm{d}}{\mathrm{d}t} a(t_p) \neq 0$ and $\frac{\mathrm{d}}{\mathrm{d}t} b(t_p) \neq 0$ then:

$$\varphi = \psi_1 - \psi_2 = \arctan \frac{\omega b(t_p)}{\frac{\mathrm{d}}{\mathrm{d}t} b(t_p)} - \arctan \frac{\omega a(t_p)}{\frac{\mathrm{d}}{\mathrm{d}t} a(t_p)} . \tag{12}$$

Because of inverse trigonometric functions features the phase shift calculated according to eq. (7) and (8) should be calculated as follows:

$$\varphi = \psi_1 - \psi_2 - k \cdot \frac{\pi}{2} . \tag{13}$$

The coefficient k depends on ψ_1 and ψ_2 signs. For phase shift between the signals $a(t)$ and $b(t)$ which is greater than 0 it can be calculated as follows:

$$k = \operatorname{sgn}(\psi_1 \psi_2 + 1) - 1 . \tag{14}$$

The diagram of signals processing according (11) is shown in Fig.1.

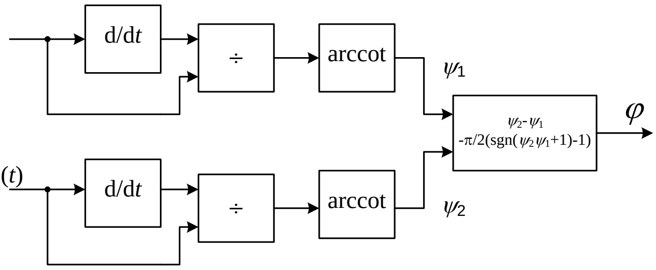

Fig.1. A diagram of signal processing in the proposed algorithm

Respectively, the diagram of signals processing according to eq. (12) is shown in Fig.2.

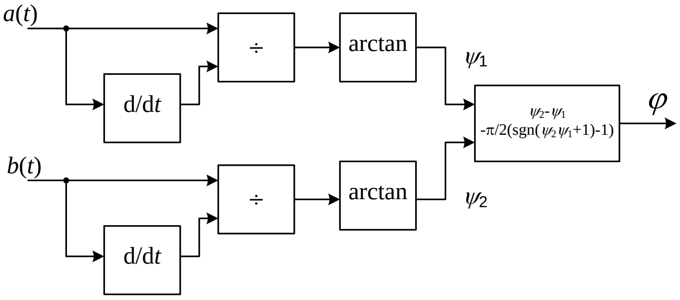

Fig.2. A diagram of signals processing of proposed algorithm

3. VIRTUAL IMPLEMENTATION

The LabVEW packet allows building virtual instruments very easily. The virtual realisation of the instrument for phase shift measurement according to eq. (11) and (12) is shown in Fig.2.

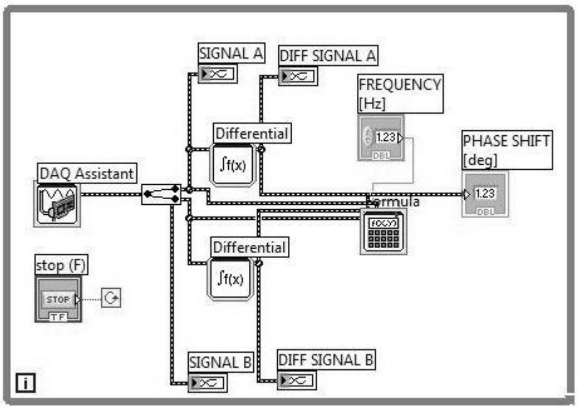

Fig.2. A diagram of the LabVIEW virtual implementation of the proposed algorithm

The virtual instrument uses the PersonaDaq55 USB data acquisition card, which is represented on the block diagram (Fig.2) by the DAQ Assistant block. The signal A is a sampled signal $a(t)$ and the signal B is a sampled signal $b(t)$

respectively. Both signals are connected to differential blocks. The signals A and B and output signals of the differential blocks are connected to the Formula block, which calculates the phase shift according to eq. (12) with the correcting coefficient given by eq. (14). All signals can be visualized on virtual scopes. The output of the Formula block is connected to the output indicator.

The LabVIEW packet generates a front panel of the virtual instrument, which is shown on Fig.3. The front panel indicates the measured phase shift and allows changing frequency of measured signals. The signals and their derivatives are visualized on the scopes below. It is possible to measure the phase shift up to 50 Hz in the realised meter because of low sampling frequency of PersonaDaq55 USB data acquisition card. Such realization can be suitable for measurements in VLF frequencies range, but it is possible to measure the phase shift for signals of other frequencies. It depends on features of used data acquisition card and programming environment.

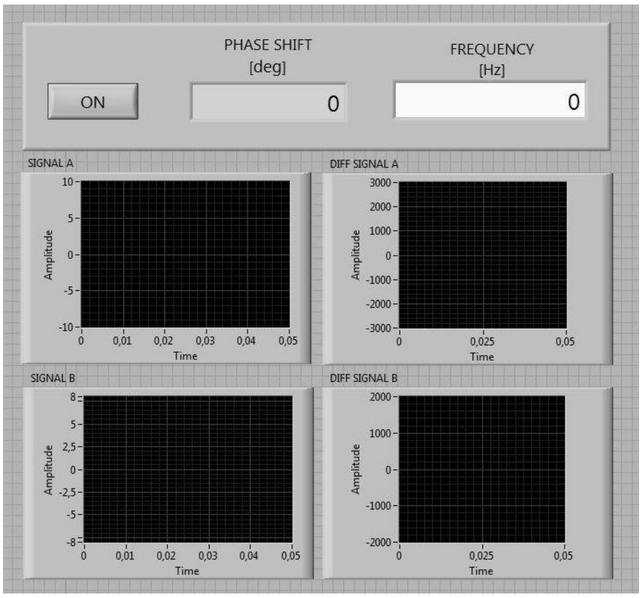

Fig.3. The front panel of the realised virtual meter

The meter has been investigated for 50 Hz frequency. A signal from the sinusoidal generator Motech FG503 has been attached to a passive phase shifter. The signals from the input and the output of the phase shifter have been attached to the inputs of data acquisition card and to the inputs of a Philips PM6680 counter-timer. A maximal error in range of 0...180 deg is about 3 deg. The error depends on an accuracy of the data acquisition card and an accuracy of the LabVIEW algorithms.

4. CONCLUSIONS

Presented idea of phase shift measurements has been realised as a virtual instrument. The realisation is programmed with the LabVIEW packet. Such realisation allows simulation of the circuit and to measuring the phase shift of real signals. The realisation of presented circuit is very simple. It requires only basic signal processing blocks, i.e. the differentiation block and the formula block, which realises a simple mathematical formula described by the equation (12). The circuit can be used for the measurement of the phase shift in case of distorted signals as well, but only between fundamental harmonic. Other harmonics should be filtered and the DC component should be deleted too. The accuracy of presented circuit in real measurements is not too high. A maximal error in range of 0...180 deg is about 3 deg.

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