THE MEASURABLE QUANTITIES IN THE DOPPLER EFFECT

SHUKRI KLINAKU

Institute of Physics, University of Prishtina, Prishtina, Kosova

e-mail: klinaku@uni-pr.edu

Abstract

Usually the Doppler effect is used to measure the velocity of the wave source (or the velocity of the observer). In this paper we will show all the physical quantities that can be measured in the Doppler effect. With particular emphasis we will show that in the Doppler effect we can also measure the relative velocity between the source (observer) and the wave. Using the radar gun for the measurement of the observed frequency and if we know the velocity of the wave, then we can measure the relative velocity between the wave source and the wave. The measurement of this quantity is very easily achievable. In other side, this measurement enables us the understanding of the role of relative velocity in Doppler effect – which has been neglected up to date – and hence it is very important for deep understanding the Doppler effect.

Key words: relative velocity, Doppler effect, radar gun.

Përmbledhje

Zakonisht efekti Doppler përdoret për të matur shpejtësinë e burimit (ose shpejtësinë e vrojtuesit). Në këtë punim do të tregohen madhësitë fizike që mund të maten në efektin Doppler. Me theks të veçantë do të tregohet se mund të matet edhe shpejtësia relative ndërmjet burimit (vrojtuesit) dhe valës. Duke përdorur radarin për matjen e frekuencës së vrojtuar dhe duke ditur shpejtësinë e valës, atëherë mund të matet shpejtësia relative ndërmjet burimit të valës dhe valës. Matja e kësaj madhësie është shumë lehtë e arritshme. Në anën tjetër, kjo matje na mundëson të kuptojmë rolin e shpejtësisë relative në efektin Doppler – e cila është lënë pas dore deri më sot – e kjo pastaj është shumë e rëndësishme për të kuptuar në thellësi efektin Doppler.

Fjalëkyçe: shpejtësia relative, efekti Doppler, radari.

Introduction

Since its discovery the Doppler effect (DE) has found widespread use in science and technology. We find the DE in astrophysics, industry, medicine and communication. Usually the DE is used to measure the velocity of the wave source (or the velocity of the observer). In this paper we will show all the physical quantities that can be measured in the DE. We will show that in the DE we can also measure the relative velocity between the source (observer) and the wave. Using the radar gun for the measurement of the observed frequency and if we know the velocity of the wave, then we can measure the relative velocity between the wave source and the wave. When DE is explained in textbooks the relative velocity is usually not mentioned. Even when it is mentioned, it is mentioned as relative motion between the observer and the source, or between the source/ observer and the origin of the frame of reference (or medium as wave carrier). Here we will show relative velocity between wave and source/ observer. The measurement of this quantity is very easy, on the other side it is very important for the understanding of the role of relative velocity in DE, which has been neglected up to date.

Physical quantities in Doppler effect that are in use

The DE is the change of observed frequency of a wave due to the motion of its source or observer. In the case when the observer is resting, and the wave source is moving toward the observer with velocity v, then for the DE formula we have:

$$\frac{f_o}{f_s} = \frac{c}{c-v} \tag{1}$$

where f_o is the observed frequency, f_s is the source frequency and c is the velocity of the wave. As we see in equation (1) we have four physical quantities. And it is well known that if we know in any way three of them, then we can find the fourth. The observed frequency is not the only quantity which changes in the DE. The changes of the observed wavelength λ_o in relation to the emitted wavelength λ_s; the observed period T_o in relation to the period of source T_s, the time within which *n*-wavefronts will be received by the observer t_o in relation to the time within which *n*-wavefronts are emitted by the source t_s - are presented in the following three equations:

$$\frac{\lambda_s}{\lambda_o} = \frac{c}{c-v} \tag{2}$$

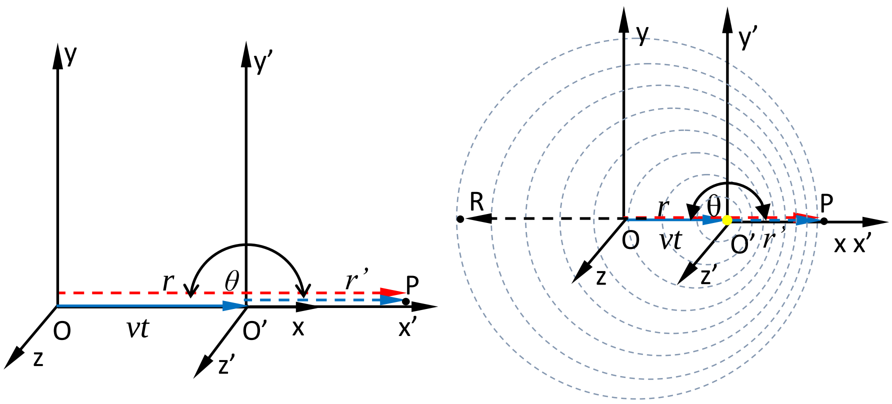
$$\frac{T_s}{T_o} = \frac{c}{c-v} \tag{3}$$

$$\frac{t_s}{t_o} = \frac{c}{c-v} \ . \tag{4}$$

The last equation presents the time Doppler effect, and this equation cannot be found in modern physics, except in the works of the author of this paper (Klinaku, 2015; Klinaku 2017; Klinaku & Berisha, 2019). We find the DE expressed also by means of energies (for example instead the frequencies, we find the energies), but in recent decades very rarely we find this form of expression.

Relative velocity between wave and wave source/ observer

Let's take two bodies moving in the same direction relative to a resting observer (Fig. 1*a*). As we know, a resting observer (at origin O) can identify the relative velocity which combines the velocities of these two bodies (frame of reference with origin O' and particle P). The relative velocity for



a *b*

Figure 1. The simplest relative motion (*a*); the Doppler effect (b).

this situation is:

$$u_{uv} = u - v \tag{5}$$

where u is the velocity of point P relative to O, v is the velocity of O' relative to O, and u_{cv} is the velocity of P relative to O'.

Now let us assume that the source of waves is at the origin of system O' and that P represents the point reached by the wavefront (Fig. 1*b*). In this case, the two bodies which move relative to origin O are the wave source (instead of frame of reference with origin O' in Fig. 1*a*) and the wavefronts (instead of particle P in Fig. 1*a*); and as we see Fig. 1*a* is transformed into Fig. 1*b*. It is clear, that now we are dealing with the DE (Fig.1*b*). Since the skeleton of Fig. 1*b* is that of the relative motion previously discussed (Fig. 1*a*), then the equations of relative motion are also valid for the DE.

In other words, DE is a typical relative motion, except that in DE we have to deal with specific physical quantities (Klinaku, 2017; Klinaku 2019 *a*). And if we want to find the relationship between the velocities of the wavefronts and the velocity of the wave source, then we use equation (5). If we take the velocity of wave c instead of velocity u; the velocity of O' is now the velocity of the source v; then the relative velocity between wavefront and source is:

$$u_{cv} = c - v \ . \quad (6)$$

It is clear, that equation (6) relates to Fig. 1*b*, because of that we can substitute it in the DE formula (1), and this equation will be transformed like this:

$$\frac{f_o}{f_s} = \frac{c}{u_{cv}} \ . \quad (7)$$

Equation (7) can be obtained also in other way (Klinaku & Berisha, 2019). Now in the DE formula we have a new physical quantity – that is relative velocity between the wave and its source u_{cv} which can also be measured, if we know the other quantities of equation (7):

$$u_{cv} = c\frac{f_s}{f_o} \ . \quad (8)$$

This assertion can be easily proved by making measurements according to equation (8) and comparing them with the calculations obtained from equation (6). According to equation (8), if we measure with a radar gun the observed frequency f_o from a moving source, then knowing the velocity of electromagnetic wave *c* and the frequency of the source f_s, then we can find the relative velocity between wave and source u_{cv}. Now according to equation (6), knowing the velocity of the wave source *v* we calculate relative velocity between the wave and source u_{cv}, and we will find the same value for it.

So far, this problem has been treated only for the longitudinal case. However, the claim of this paper is valid for the three-dimensional case as well (Klinaku, 2019 *b*). Determining and using relative velocity (equations 6 and 8) is very simple, however it is important for deep understanding of the DE, even of relative motion. By determining the true role of relative velocity between wave and source/ observer it is found that observed quantities (frequency, wavelength etc.) are varying depending on this velocity. This then affects the reconsideration of relative motion (relativity). While the practical importance of defining of relative velocity u_{cv} is the verification and calibration of the Doppler instruments.

Why isn't the relative velocity between wave and source/ observer in the Doppler effect in use in modern physics?

Since the presence of the relative velocity between wave and source/ observer in DE is easily explainable and measurable, then readily we pose the question: why isn't this relative velocity in DE in use in modern physics? The first answer on this would be as follows. As we know, according to the special theory of relativity (STR) the relative velocity between *u* and *v* is:

$$u_{cv} = \frac{u - v}{1 - \frac{uv}{c^2}} \tag{9}$$

and in the case when $u = c$, for u_{cv} we have:

$$u_{cv} = \frac{c - v}{1 - \frac{cv}{c^2}} = c \ . \tag{10}$$

In this case there would be no DE at all, because equations (7 and 8) will give us $f_s = f_o$. In other words, if the relative velocity between the electromagnetic waves and their source/ observer would be equal to the velocity of the electromagnetic waves (*c*), then the DE would never occur for this kind of waves. Thus, as we see, such application of this little truth would disturb modern physics. That is why the relative velocity between wave and source/ observer in DE isn't in use in modern physics.

Conclusion

In this paper is showed that in the DE formula besides the usual physical quantities (frequency, wavelength, velocity of wave, velocity of source/ observer, period, time, energy) a very important physical quantity is involved: relative velocity between wave and source/ observer. The definition of this physical quantity is easily explainable and measurable. The relative velocity between the wave and the source/ observer is key to a deep understanding of the DE, even of the relative motion.

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