Standardised Energy Loss (SEL) during Euro Coinage Collisions (ECC)

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We analyse energy losses generated during inelastic collisions of 50¢ euro coins. The concept of euro coinage collision (ECC) is then generalised to all other euro coins of the same materials.

Introduction

Collisions are everywhere. There are two types of collisions known to mankind; elastic and inelastic. In the year 2017 the total world energy consumption was estimated to be 13511 megatons of oil equivalent by the BP and is constantly increasing [1]. Therefore it is our perrogative to minimise energy losses around the world to ensure that the energy we produce isn't wasted.

Elastic collisions are known to be energy-efficient, since mechanical energy is preserved. On the other hand, inelastic collisions, while obeying the law of conservation of momentum, do not conserve mechanical energy and are in this regard considered to be "lossy". Many collisions in nature and everdyday life are inelastic, *exempli gratia* car crashes and coin clashes [2].

The euro is legal tender in 19 of 28 European Union member countries. It was first introduced on 1 January 1999 as a virtual currency, but only on 1 January 2002 were physical banknotes and coinage brought in. Nowadays the currency is used by some 338.6 million people every day [3]. It is only obvious that many coin clashes occur due to this fact every day. We term these everyday coin clashes Euro Coinage Collisions (ECC) and want to investigate the waste of energy, which we call Standardised Energy Loss (SEL).

SEL Method

The method we developed is quite complicated in theory but in the spirit of ecology made very accessible and cost-effective by us. The equipment we used consists of 20¢ and 50¢ euro coins, a caliper, a $80\ g/m^2$ $0.5\ cm$ square grid paper, a pencil, two rulers and a stopwatch. The first step is measuring the coefficient of friction between the euro conins and the paper. We measured the time of a coin's slide down the slope covered with previously stated paper type. Also we measured the height and the length of the slope. We used this method to measure the force of friction stopping the coin down the slope. Afterwards we arranged two coins on the paper approximately 7 cm appart and we circled them with a pencil, we also circled when the second coin was touching the first, as it would when impacting it. And we also circled that coin, later we drew the centers of each circumference (see Fig. 1). To measure the coin impact energies, we set the two coins into the initial positions and launched one into the another. We assumed that the relative SEL is not affected by initial speed, therefore launching the first coin with constant speed wasn't necessary. After the impact we measured the distances travelled by both coins and their trajectories' respective angles relative to the incident line.

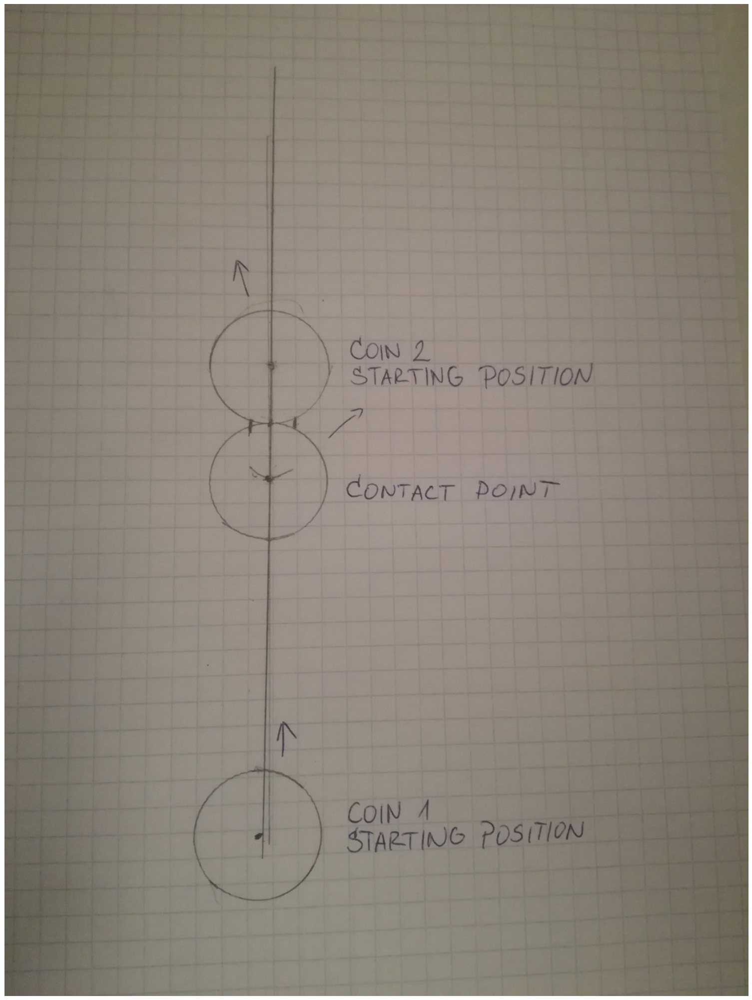

Figure 1: Correctly annotated paper used in our experiment

Another method that was suggested was to constrain the motion of the coins between two rulers, so that the significant angles are 0 or equivantly only one dimension of motion is observed. We will refer to this as the "ruler method" from now on.

Thirteen measurements of the previous kind were made, while 10 of the latter kind were made in addition to those.

Data processing

The velocity of the incident coin before impact is denoted v, the mass of the 50¢ coin was found to be $m = 7.8\ g$, the post-impact starting velocities are denoted v_1 and v_2, the respective distance travelled d_1 and d_2, and the respective angles relative to the incident line α_1 and α_2. The coefficient of dynamic friction was found to be $\mu = 0.805$.

From the law of conservation of momentum we have:

$$mv = mv_1 \cos\alpha_1 + mv_2 \cos\alpha_2$$
$$v = v_1 \cos\alpha_1 + v_2 \cos\alpha_2 \tag{1}$$

From the law of conservation of energy we have:

$$E_{initial} = \frac{1}{2}mv^2 = \frac{1}{2}m(v_1^2 + v_2^2) + C\ , \tag{2}$$

C denoting the energy loss during ECC.

Due to work done by kinetic friction ($W_i = mg\mu d_i$), we have from the equations of motion:

$$v_i^2 = 2ad_i$$
$$v_i^2 = 2g\mu d_i \tag{3}$$

We insert (1) and (3) into (2) to obtain:

$$\frac{1}{2}m(v_1 \cos\alpha_1 + v_2 \cos\alpha_2)^2 = mg\mu(d_1 + d_2) + C$$
$$C = m(\frac{1}{2}(\sqrt{2g\mu d_1}\cos\alpha_1 + \sqrt{2g\mu d_2}\cos\alpha_2)^2 - g\mu(d_1 + d_2)) \tag{4}$$

and

$$E_{initial} = \frac{1}{2}m(\sqrt{2g\mu d_1}\cos\alpha_1 + \sqrt{2g\mu d_2}\cos\alpha_2)^2 \tag{5}$$

We then define the SEL coefficient k_{SEL} to be:

$$k_{SEL} = \frac{C}{E_{initial}} = \frac{(\sqrt{d_1}cos\alpha_1 + \sqrt{d_2}cos\alpha_2)^2 - d_1 - d_2}{(\sqrt{d_1}cos\alpha_1 + \sqrt{d_2}cos\alpha_2)^2} \tag{6}$$

We carried out 23 measurements in total and compiled C and $E_{initial}$ with formulas 4 and 5 for each one. We differentiated the measurements obtained through our original method from the ones obtained through the ruler method. A two-tailed unpaired t-test of k_{SEL} values was carried out between these two data sets.

Data presentation

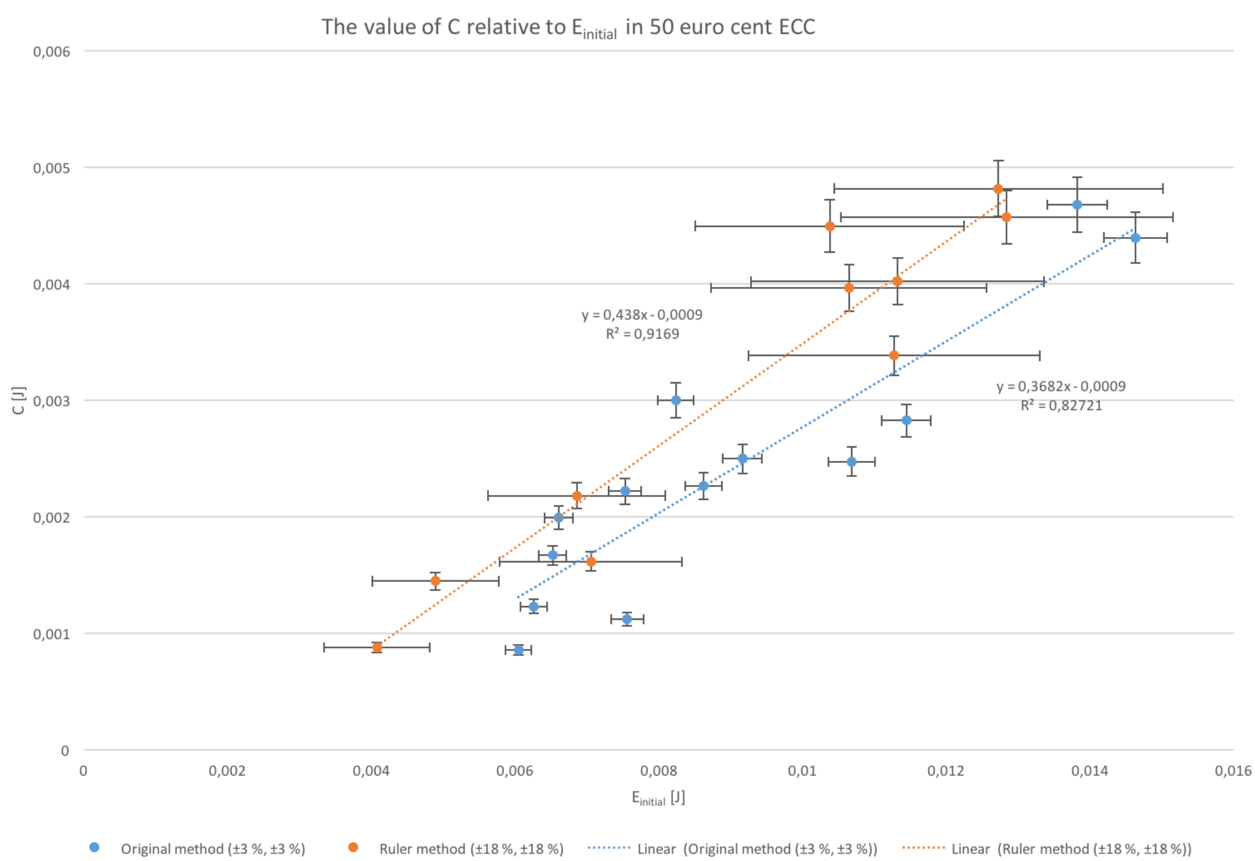

Figure 2: The value of C relative to $E_{initial}$ in 50¢ ECC

	average k_{SEL}	standard deviation	p-value
original method	0,258	0,067	0,027
ruler method	0,326	0,068	

Table 1: Statistical analysis of k_{SEL} relative to method

Discussion

From Fig. 2 a positive linear correlation between C and $E_{initial}$ can be observed. This correlation was found to hold true regardless of the method as both $R^2 > 0.50$. The slope of the BLF represents the thus derived SEL coefficient k_{SEL}. Another way of computing the SEL coefficient k_{SEL} is presented in Table 1, that is the average of k_{SEL} computed with Equation 6. Due to the fact that BLF uses the method of least squares, we conclude that its SEL coefficient is closer to the true value.

The SEL coefficient computed from the data obtained from the ruler method was visibly greater than the one derived from the original method. We expect that to be because of additional energy losses due to friction between the coins and the rulers.

We conclude that during a 50¢ ECC about 37 % of initial energy is lost in heat and sound, which is easily observable by ear. Because there is no mass in the expression for the SEL coefficient, we propose that the value previously stated holds for all euro coins, but additional experiments would have to be carried out to confirm this.

Conclusion and Evaluation

As expected the amount of energy lost during ECC is significant, which we can expect to hold for other major coinage with similar properties as well. This should act as a reminder for all kinds of inelastic collisions around the world. Consequently, more research should be made into conservation of mechanical energy in colisions.

More precise measuremens of the distances made by coinage after the impact should be made since measurements obtained from the ruler method have uncertainties up to 18 %. The correlation between the mass and the SEL coefficient would also have to be researched more thoroughly in future experiments in order to confirm our conjecture made in the Discussion.

References and Notes

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