Investigation of a Pull Back Toy Car: a Problem of a Competition Used in a Popularizing Experimental Course

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Abstract

An amusing experimental problem of a Hungarian competition (National Competition for Secondary School Pupils) and its solution are presented. This is a nice example of interesting problems used in a special measuring course organized to popularize physics and give more experimental practice for IPhO participants.

1 Introduction

Physics competitions have a more than hundred years old tradition in Hungary. Perhaps this is one of the main reasons that Hungarian pupils achieve very good results (especially if it is compared to the size of the country) in IPhO and in other international competitions. Another important factor is the traditionally high level of math and physics education. This tradition originates in the beginning of the 20th century and it is alive in the best secondary schools up to now.

The pupil's mathematical background allows solving difficult physics problems in the school. But the strong usage of math has disadvantages, too. The problems are often quite theoretical, without any relation to everyday phenomena. Experiments and measurements are rare in the schools (partly because of the bad financial situation).

In the middle of the nineties it was observed that Hungarian IPhO participants are very good in theoretical problems but have moderate results in the experimental competitions. We decided to lay emphasis on experimental training at the preparation and selection of the IPhO team.

A special measuring course was organized in the Institute of Physics, Budapest University of Technology and Economics. Every year about forty pupils have the possibility to solve nice experimental problems with the help of a tutor. The aim of this course is not only to prepare the IPhO team but to popularize physics. The problems should be interesting and inspiring.

Inventing an experimental problem and producing a lot of uniform copies of the apparatus is neither easy nor cheep. Experimental setups of earlier competitions are therefore valuable for physics teachers. Some possibilities to use an experimental problem of a competition were suggested on the 2nd Congress of WFPhC (Groningen, 2004) [1], [2].

In this paper an experimental problem of the National Competition in Physics for Secondary School Pupils is discussed. The Institute of Physics organizes for more then ten years the experimental round of this competition. This problem – the investigation of a pull back toy car – is ideal for the popularizing measuring course. After the original text of the competition problem the solution and discussion of the measurement are presented.

2 The experimental problem[1]

In this measurement a pull back toy car is investigated. The spring in the car can be wound up by pulling back the car (for sufficient friction the car must be pressed). The released toy car is accelerated by the spring. When the energy of the spring is used up the car rolls free.

Apparatus

- A pull back toy car with a mass of 153 g
- A course, assembled from three parts, covered by cork
- 10 wooden bricks for elevating the course
- a pulley with support
- 2 cupper cylinders, 500 g each
- 10 small cylinders with hooks, 50 g each
- 2 light sensors (“START” and “STOP”) with timing electronics
- A power supply
- An aluminum “flag”
- A paper measuring band, 3 rulers
- Modeling clay, masking tape, thread
- Paper, graph paper

Task 1: Investigation of the transmission

There are two different cogwheel transmissions between the back wheels and the spring. One of them connects the back axis with the axis of the spring when the car is pulled back, the other one when the spring accelerates the car. (When the car rolls free none of them is used.)

Measure the ratio of the two different transmissions.

Task 2: Measuring the force and the work needed to pull back the car

a) *Measure and plot the force needed to pull back the car versus the pull-back distance.*
- Mount the pulley at the end of the course.
- For increasing the friction between the wheels and the course use one or two cupper cylinders. The cylinders can be fixed by modeling clay.
- At any pulling force let the car roll back slowly from the original position to the equilibrium.

b) *Estimate and plot the work needed to pull back the car versus the pull-back distance.*

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[1] It was the experimental problem of the National Competition in Physics for Secondary School Pupils, Budapest, Hungary, 15th April 2000. The time available was 4 hours. The problem was invented and assembled in the Institute of Physics, Budapest University of Technology and Economics.

Task 3: Measuring the work of the spring

a) *Measure the (whole) way of the car versus the pull-back distance.*
- Mount the course as shown in Fig. 1.a. The “braking slope” of 7 degrees is needed because there is not enough place.
- Start the car always from the same position. Mark this position on the course.

Fig. 1.a

b) *Measure and plot the way of the car versus the height of the starting position.*
- Mount the course as shown in Fig. 1.b. Let the “braking slope” be the same.
- The “accelerating slope” can be adjusted by wooden bricks.
- Start the car without pulling back from the same starting position as in task 3.a.

Fig. 1.b

c) *Using the results of tasks 3.a and 3.b estimate and plot the work of the spring used for acceleration versus pull-back distance.*

Task 4: Investigation of the motion of the car

a) *After pulling back by 15 cm release the car. Measure and plot the displacement of the car versus time.*
- At this measurement let the course be horizontal.
- The aluminum “flag” can be fixed by masking tape on the car.
- For time measurement place the light sensors on the course. When the “flag” covers the light of the sensors “START” and “STOP” the clock will be started and stopped respectively. For the correct function of the timer place the sensors at least 5 cm from each other. The time is measured in milliseconds.
- Because the time available is limited, measure only the first 1 meter of the motion.

b) *Measure the velocity of the car versus the displacement of the car.*
- Consider the remarks at task 4.a.

c) *Using the displacement versus time and velocity versus displacement data measured in tasks 4.a and 4.b plot the velocity of the car versus time.*

d) *Using the velocity versus time graph calculate and plot the acceleration of the car versus time. From the graphs determine the way where the spring worked.*

3 The solution of the problem expected at the competition

3.1 The difficulties of the measurement

The problem is inspiring, interesting and simple; the competitors don't need difficult theories or mathematical apparatus. The equipment is easy to handle; the tasks are well defined and detailed.

But carrying out the measurement has a lot of difficulties. The toy car is a cheep mass product with an imperfect mechanism: the cogwheels have friction and play, the car doesn't roll in a straight line. Therefore the scattering of the measured data can be significant; repeated measurements and error estimation are necessary.

It is quite unusual for pupils that e.g. the acceleration of the car is not constant, the plots are not linear and therefore graphic methods are required. (The physics in the school – in spite of the expanding possibilities provided by informatics – is still *linear*.)

The time available is limited; only competitors with measuring experience and routine have chance to solve the whole problem. For correct results carefully adjusted measuring arrangements and small "tricks" are needed.

3.2 The solution of the problem

Task 1: Investigation of the transmission

This is the only question where we know the exact answer: opening the car (what was for competitors forbidden) we can count the cogs of the cogwheels. The transmission is 5/8 when the spring is wound up and 65/444 when the spring accelerates the car. So the ratio of the transmissions is $111/26 \approx 4.269$.

The competitors should pull back the car and then let it roll slowly forward. The measured data are plotted on Fig. 2. The slope of the fitted line gives the asked ratio, which is – because of the friction and play of the cogwheels – smaller then the real value.

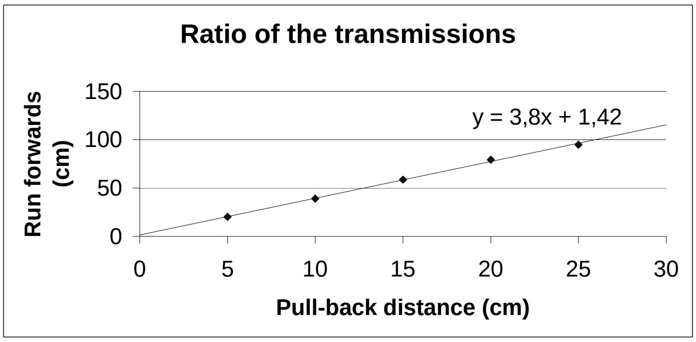
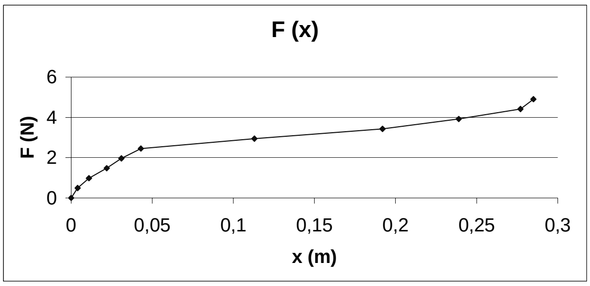


Fig. 2

Task 2: Measuring the force and the work needed to pull back the car

The measurement of the force – according to the detailed description – is simple. For accurate data (Fig. 3) at least three measurements are needed. The work (Fig. 4) can be determined by numerical integration (estimation of the area under the curve on the force versus pull-back distance graph).

A typical failure is to identify the work with the change in the potential energy of the small cylinders: when we let the cylinders pull back the car *slowly* our hand consumes a part of their potential energy.



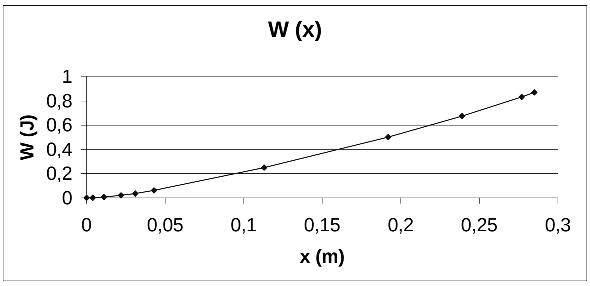
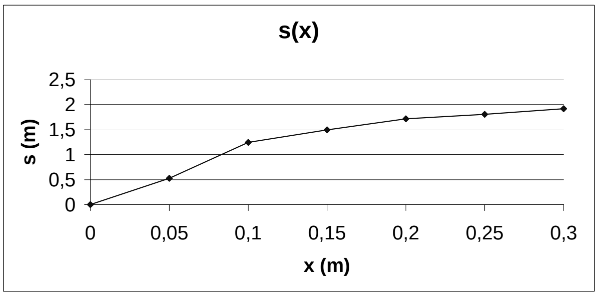


Fig. 3

Fig. 4

Task 3: Measuring the work of the spring

The measurement of the car's way versus pull-back distance and the height of the starting position has no difficulties. The averages of three measurements are plotted on Fig. 5 and 6 respectively.



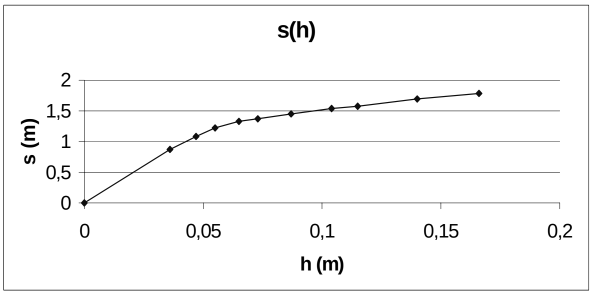


Fig. 5

Fig. 6

The work of the spring (Fig. 7) can be determined from these data. The height of the starting position according to a given way can be estimated by interpolation or can be reed from the graph. The work of the spring is about 30-40 % of the work we needed to wind up it.

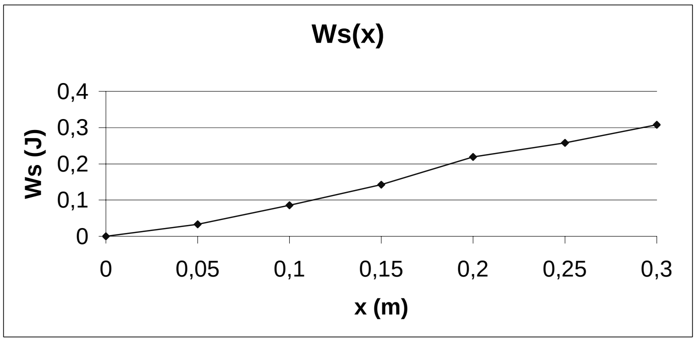


Fig. 7

Task 4: Investigation of the motion of the car

For measuring the displacement versus time graph (Fig. 8) the light sensor "START" should be mounted directly in front of the flag on the car. Bad positioning causes big error because the car has here the smallest velocity. The light sensor "STOP" should be mounted at a distance of *x* from the starting sensor.

The velocity versus time graph could be determined from the displacement versus time graph by numerical differentiation but because of the inaccurate data it is better to make separate measurements. The two sensors should be mounted at a fix small distance (5 cm) from each other and move them together. The velocity versus time graph (Fig. 10) can be determined from the velocity versus displacement (Fig. 9) and the displacement versus time graphs – similarly as the spring's work graph in task 3.

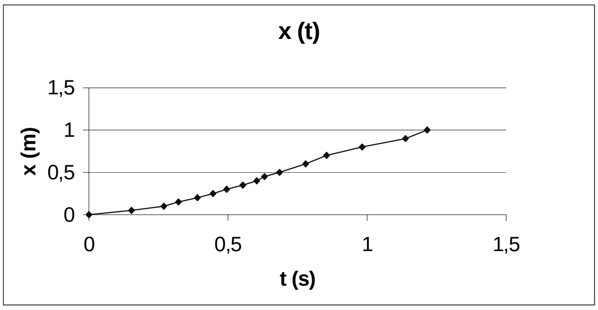


Fig. 8

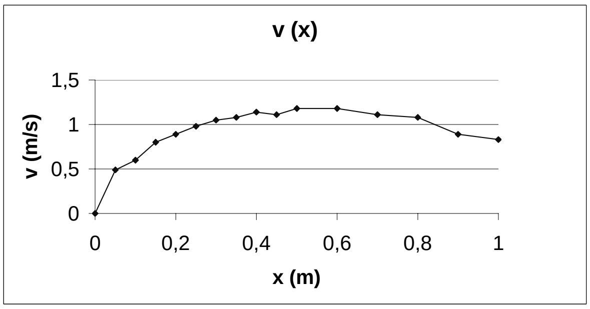


Fig. 9

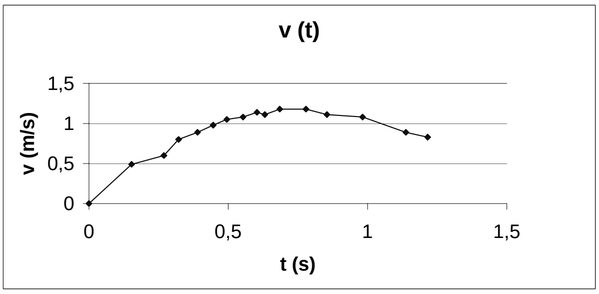


Fig. 10

The acceleration can not be measured directly. The acceleration versus time graph (Fig. 11) can be determined from the velocity versus time graph by numerical differentiation. It is interesting to plot the acceleration versus displacement graph (Fig. 12), too. We can see that the acceleration is positive on the first 55-60 cm. This is the way where the spring works. Comparing this way with the pull-back distance of 15 cm we can get a good value for the ratio of the transmissions.

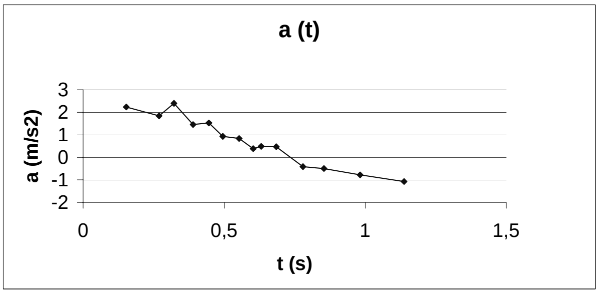


Fig. 11

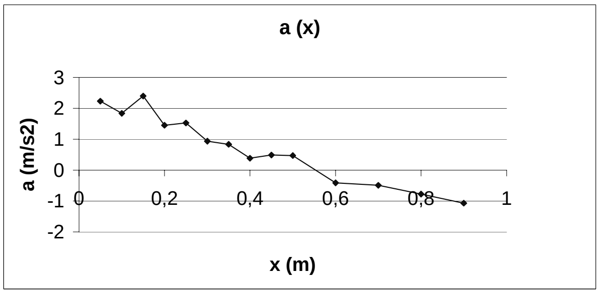


Fig. 12

3.3 Results of the experimental competition

Because of the differences between toy cars a wide range of numerical values were accepted – if the results were consistent.

This experimental competition is the last round of the National Competition. 20 pupils are selected after two theoretical rounds. From the 20 competitors the best 3 achieved more then 87 % of the possible marks, 13 pupils performed between 45 and 72 % and 4 pupils less then 37 % [3].

4 The popularizing experimental course

4.1 The concept of the experimental course

The twofold aim of the course is to give experimental practice to the member of the Hungarian IPhO team and to popularize physics among secondary school pupils. Interesting experimental problems of earlier competitions are solved and discussed – but in contrast to the competitions two pupils work together and the time available is also extended. (The pull back toy car is measured for two times three hours e.g.)

If it is needed a tutor helps the pupils to understand the theoretical background or the proper usage of the apparatus. Short introductions into error estimation and for commonly used equipments (multimeter, power supply, wave generator etc.) are provided.

The participants summarize their results with tables and plots; make calculations and error estimation – as in real competitions. These papers are corrected by the tutor and discussed together.

At the end of the semester a demonstration of spectacular experiments is organized. Inspiring phenomena are presented: materials and equipments which are in secondary schools usually not available (liquid nitrogen, high magnetic field e.g.).

4.2 Summary

The most important profit of the course is the course itself: the good atmosphere during the measurements, the joy of playing physics. But the course has two other important outcomes.

A significant part of the earlier participants studies physics – a lot of them in our institute – what proves the effectiveness of the popularization. The measuring experience is very useful during the studies.

The experimental and theoretical results of the Hungarian participants on IPhO became much more balanced. It can be declared that the experimental course have also contributed to the outstanding Hungarian successes of the last years: In 2004 *Péter Kómár* won the special prize for the best experimental work of the 35th IPhO in Pohang, South Korea [4] and in 2005 *Gábor Halász* – together with *Ying-Hsuan Lin* from Taiwan – was absolute winner of the 36th IPhO in Salamanca, Spain [5].

5 References

[1] P. Vankó: An Experimental Problem of a Competition Discussed in a Secondary School Workshop
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[2] P. Vankó: An Experimental Problem of a Competition Discussed in a Secondary School Workshop
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[3] Vannay L., Vankó P., Fülöp F., Máthé J. and Nagy T.: A fizika OKTV harmadik fordulója a harmadik kategória részére 2000
Módszertani Lapok Fizika **7** no2 pp14-26 (2000, *in Hungarian*)

[4] 35th IPhO home page: http://www.ipho2004.or.kr/home/eng

[5] 36th IPhO home page: http://www.ipho2005.com/