Mechanics

Translational motions of a mass point
Conservation of linear momentum

LD Physics Leaflets

P1.3.4.4

Newton's third law and laws of collision

Recording and evaluating with VideoCom

Objects of the experiments

- Recording the path-time diagrams for elastic collisions of two gliders with VideoCom.
- Confirming the conservation of linear momentum and Newton's third law.

Principles

One-dimensional elastic collision:

Newton's third law (interaction law) says: *"The actions exerted by two mass points on one another, i.e. forces and momenta of forces, always have equal magnitudes and opposite directions (action and reaction)."* It is most easily verified by considering one-dimensional collisions of two equal or different masses m_1 and m_2. An important consequence is the momentum conservation law. If the second mass is at rest before the collision ($v_2 = 0$), it reads:

$$p_1 = m_1 \cdot v_1 = m_1 \cdot v'_1 + m_2 \cdot v'_2 = p'_1 + p'_2 \qquad \text{(I).}$$

In an elastic collision, the sum of the kinetic energies before and after the collision is equal, too:

$$E_1 = \frac{m_1}{2} \cdot v_1^2 = \frac{m_1}{2} \cdot v'^2_1 + \frac{m_2}{2} \cdot v'^2_2 = E'_1 + E'_2 \qquad \text{(II).}$$

From (I) and (II) the following expressions are derived for the velocities, momenta and kinetic energies of the two masses after the collision:

$$v'_1 = \frac{m_1 - m_2}{m_1 + m_2} \cdot v_1,\ v_2{}' = \frac{2 \cdot m_1}{m_1 + m_2} \cdot v_1 \qquad \text{(III)}$$

$$p_1{}' = \frac{m_1 - m_2}{m_1 + m_2} \cdot p_1,\ p_2{}' = \frac{2 \cdot m_2}{m_1 + m_2} \cdot p_1 \qquad \text{(IV)}$$

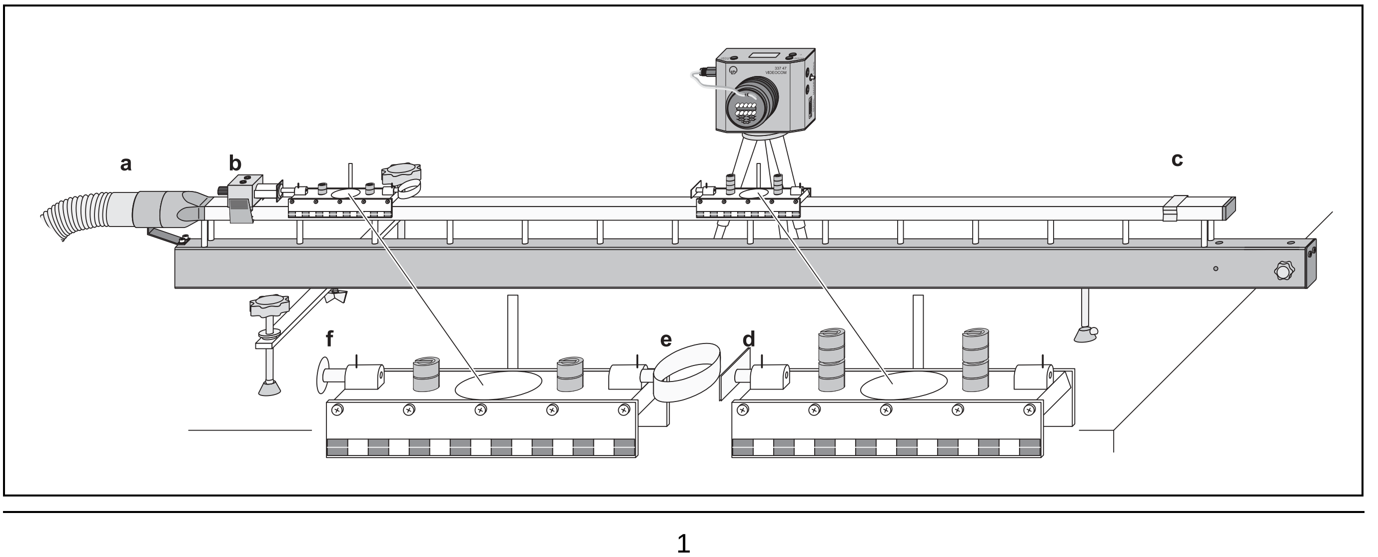
$$E'_1 = \left(\frac{m_1 - m_2}{m_1 + m_2}\right)^2 \cdot E_1,\ E'_2 = \frac{4 \cdot m_1 \cdot m_2}{\left(m_1 + m_2\right)^2} \cdot E_1 \qquad \text{(V)}$$

Recording the motions with VideoCom:

In the experiment, the elastic collisions of two gliders on a linear air track are recorded with the single-line CCD camera VideoCom, which illuminates a retroreflecting foil attached to the glider with LED flashes and images the reflected flashes on a CCD line with 2048 pixels with a camera lens (CCD: charge-coupled device). Up to 80 times per second the present positions of the gliders are transferred to a computer via a serial interface.

A computer program for VideoCom represents the entire motion of the gliders as a path-time diagram and makes possible

Fig. 1 Experimental setup for recording motion with VideoCom.



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Apparatus

1 linear air track	337 501
1 air supply for air track	337 53
1 power controller	337 531
1 VideoCom	337 47
1 camera tripod	300 59
1 metal scale	311 02
additionally required:	
1 PC with Windows 95 / 98 / NT	

further evaluation of the measured values. In particular, computation of the velocity and of the acceleration

$$v(t) = \frac{s(t+\Delta t) - s(t-\Delta t)}{2 \cdot \Delta t} \text{ and } a(t) = \frac{v(t+\Delta t) - v(t-\Delta t)}{2 \cdot \Delta t}$$

can be activated with a mouse click, whereby the user has a choice between several time intervals Δt. If the smallest possible value Δ*t* = 12.5 ms is selected, the collision itself can be observed as it takes somewhat more than 60 ms.

Setup

The experimental setup is illustrated in Fig. 1.

Setting up the linear air track:

– Mount the track rail on the track stand, set it up, and align it horizontally with the adjusting screws (see instruction sheet of the linear air track) using a spirit level.
– Plug the adapter for air supply **(a)** into the air inlet.
– Connect the air supply to the power controller; connect the tubing to the adapter for air supply (see instruction sheet of linear air track).
– Attach the holding magnet with a clamping rider **(b)** near the air inlet, and put the brake **(c)** onto the other end of the track.
– Switch the air supply on, put the glider on the linear air track, and readjust the track with the adjusting screws until the glider remains at rest at several places of the track rail; the air flow should be varied until the parameters are optimised.

Setting up VideoCom:

– Screw VideoCom onto the camera tripod, set it up at a distance of approx. 2 m from the linear air track, and align it in height with the linear air track parallel to the track rail.
– Supply VideoCom with power via the plug-in unit, and connect it to a serial input of the PC (e. g. COM1).
– If necessary, install the VideoCom software on a PC, call the program “VideoCom Motions” and, if necessary, choose the desired language and the serial interface (see instruction sheet of VideoCom).

Aligning VideoCom:

– Equip two gliders with interrupter flags and stick retroreflecting foil on both of them.
– Move the glider 1 to the holding magnet, and put the glider 2 on the linear air track while the air supply is switched off so that the distance between the two interrupter flags is exactly 1 m.
– Click “Intensity Test” in the program “VideoCom Motions”.
– Align VideoCom so that two peaks are visible on the LC display on the housing of the camera or on the screen respectively.
– Slightly darken the room in order to minimise the background.
– Get rid of interfering light or reflections so that no other peaks are visible.
– Improve the alignment further until the ratio between the peaks and the background is greater than 5 : 1 for both gliders.

Compensating the distortion:

– Change to the representation “Path” in the program “VideoCom Motions”.
– Equip one glider with both interrupter flags (distance = 5 cm).
– Call the menu “Settings/Path Calibration” with the button or the key F5.
– Enter the values 0 m and 0.05 m as positions of the two interrupter flags in the register “Path Calibration”.
– Click the button “Read Pixels From Display” and activate “Use Calibration”.
– Call the menu “Settings/Path Calibration” anew and enter the following settings in the register “Setpoint Selection”.

Δt	12.5 ms (80 fps)
Flash	Auto
Smoothing	Minimum (2*dt)
Stop measurement	Via Start/Stop Key

– Start the measurement with the button or the key F9, and record the motion of the glider.
– Next click the button “Suggest Linearisation” in the register “Linearisation” of the menu “Settings/Path Calibration”.
– If an angle $\alpha \neq 0°$ is displayed, the angle between the linear air track and VideoCom is not yet correct:
– Reject the linearisation with the button “Interrupt”.
– Adjust the position of the linear air track by displacing the “right foot”.
– Delete the old measured values with the button or the key F4, record the motion of the glider, and determine the angle α anew.
– Repeat the procedure until $\alpha = 0°$ is displayed; then activate “Use Linearisation” and take on the displayed distortion δ.

Path calibration:

– Put one interrupter flag on each glider again.
– Equip the glider 1 with the holding plate **(f)** and the impact spring **(e)** and the glider 2 with the buffer **(d)**.
– In addition, put four 1 g weights on the glider 1 and eight 1 g weights on glider 2 so that both gliders have a weight of 100 g.
– The air supply being switched off, put the glider 1 on the track at the position 0 m and the glider 2 at the position 1 m.
– Enter the values 0 m and 1 m as positions of the two gliders in the register “Path Calibration” of the menu “Settings/Path Calibration”.
– Click the button “Read Pixels From Display”, and activate “Use Calibration”.

Carrying out the experiment

a) m_1 = 100 g = m_2 = 100 g:

– Delete old measured values with [icon] or F4.
– Position the glider 1 a 0 m and the glider 2 at 0.6 m.
– Start the measurement with [icon] or F9 and then push the glider 1 with a finger.
– Stop the measurement with [icon] or F9.
– Using the shortcut Alt+Z, activate the zoom mode, keep the left mouse button down, and draw a frame around the desired section of the path-time diagram with the mouse pointer.

Kinetic energy:

– Call the menu "Settings/Path Calibration" with the button [icon] or the key F5. Click the register "Formula", and make the following entries:

Quantity:	Energy
Symbol:	E
Unit:	mJ
Formulas:	0,5*100*v1^2
	0,5*100*v2^2
	0,5*100*v1^2+0,5*100*v2^2

– Select the minimum and maximum of the energy scale, and confirm the entries with the button "OK".

Momentum:

– Click the register "Formula" in the menu "Settings/Path Calibration", and make the following entries:

Quantity:	Momentum
Symbol:	p
Unit:	g*m/s
Formulas:	100*v1
	100*v2
	100*v1+100*v2

– Select the minimum and maximum of the momentum scale, and confirm the entries with the button "OK".

Mutually exerted force:

– Click the register "Formula" in the menu "Settings/Path Calibration", and make the following entries:

Unit:	Force
Symbol:	F
Unit:	mN
Formulas:	100*a1
	100*a2
	100*a1+100*a2

– Select the minimum and maximum of the force scale, and confirm the entries with the button "OK".
– Store the measured values with [icon] or F2 (use a filename that allows you to recognise the file).

b) m_1 = 400 g > m_2 = 100 g:

– Load the glider 1 with an additional three 100 g weights
– Delete old measured values with [icon] or F4.
– Position the glider 1 a 0 m and the glider 2 at 0.6 m.
– Start the measurement with [icon] or F9 and then push the glider 1 with a finger.
– Stop the measurement with [icon] or F9.
– Zoom in on the desired section of the path-time diagram.
– Examine the energies, momenta and the mutually exerted forces; take the changed mass m_1 = 400 g into account when considering the formulas.

c) m_1 = 100 g < m_2 = 400 g:

– Remove the 100 g weights from the glider 1 and attach them to the glider 2.
– Delete old measured values with [icon] or F4.
– Position the glider 1 a 0 m and the glider 2 at 0.6 m.
– Start the measurement with [icon] or F9 and then push the glider 1 with a finger.
– Stop the measurement with [icon] or F9.
– Zoom in on the desired section of the path-time diagram.
– Examine the energies, momenta and the mutually exerted forces; take the changed mass m_2 = 400 g into account when considering the formulas.

Measuring example and evaluation

a) m_1 = 100 g = m_2 = 100 g:

After the collision, the glider 1 is at rest and the glider 2 moves uniformly. The velocity of the glider 2 after the collision is the same as that of the glider 1 before the collision. The same is true for the momentum and the energy of the two gliders. The total momentum and the total energy before and after the collision are equal. The total momentum is also conserved during the collision (see Figs. 2, 3, 5 and 6).

During the collision, the forces exerted by the gliders on one another are of equal magnitudes and opposite directions. Newton's third law holds (see Fig. 7).

b) m_1 = 400 g > m_2 = 100 g:

After the collision, the two gliders move uniformly in the same direction (see Fig. 8). The glider 1 retains 60 % of the momentum and 36 % of the kinetic energy after the collision. 40 % of the momentum and 64 % of the kinetic energy are transferred to the glider 2 (see Figs. 11 and 12, cf. (IV) and (V)). The total momentum and the total energy before and after the collision are equal. The total momentum is also conserved during the collision.

During the collision, the forces exerted by the gliders on one another are of equal magnitudes and opposite directions (see Fig. 13). Newton's third law holds.

c) m_1 = 100 g < m_2 = 400 g:

After the collision, the two gliders move uniformly in opposite directions (see Fig. 14). The glider 1 retains 36 % of its kinetic energy after the collision, and 64 % of the kinetic energy are transferred to the glider 2 (see Figs. 17 and 18, cf. (IV) and (V)). The total momentum and the total energy before and after the collision are equal. The total momentum is also conserved during the collision.

During the collision, the forces exerted by the gliders on one another are of equal magnitudes and opposite directions (see Fig. 19). Newton's third law holds.

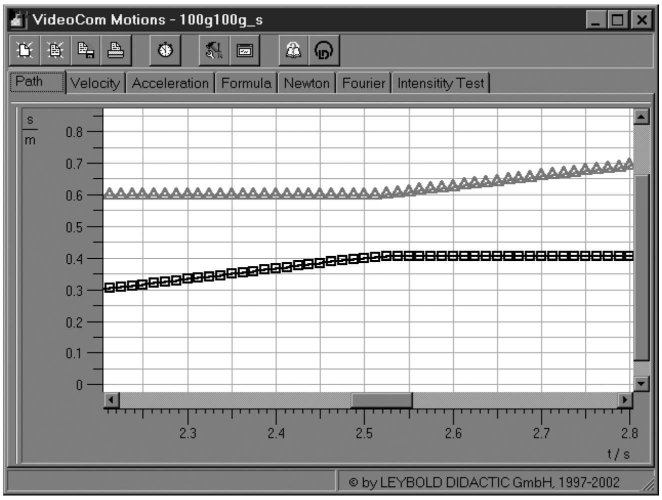

Fig. 2 Path-time diagram for m_1 = 100 g, m_2 = 100 g (□ : glider 1, △ : glider 2).

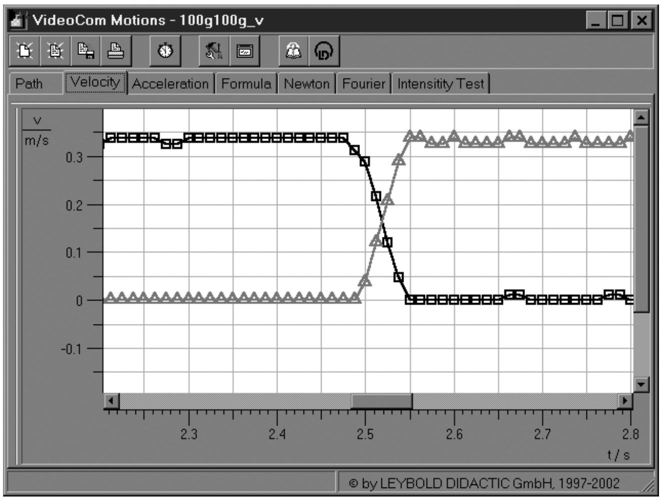

Fig. 3 Velocity-time diagram for m_1 = 100 g, m_2 = 100 g (□ : glider 1, △ : glider 2).

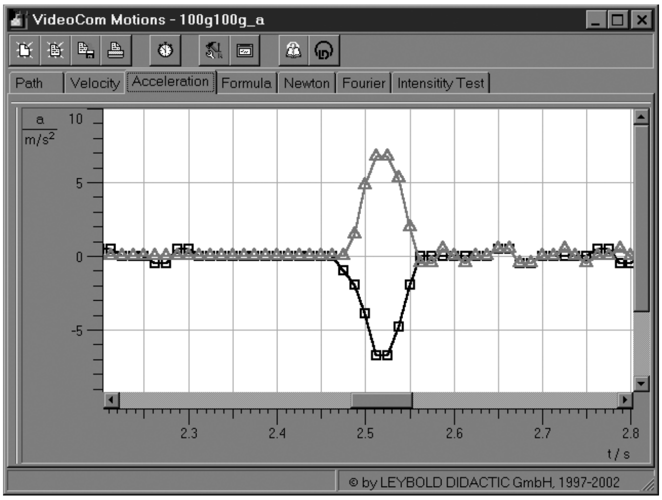

Fig. 4 Acceleration-time diagram for m_1 = 100 g, m_2 = 100 g (□ : glider 1, △ : glider 2).

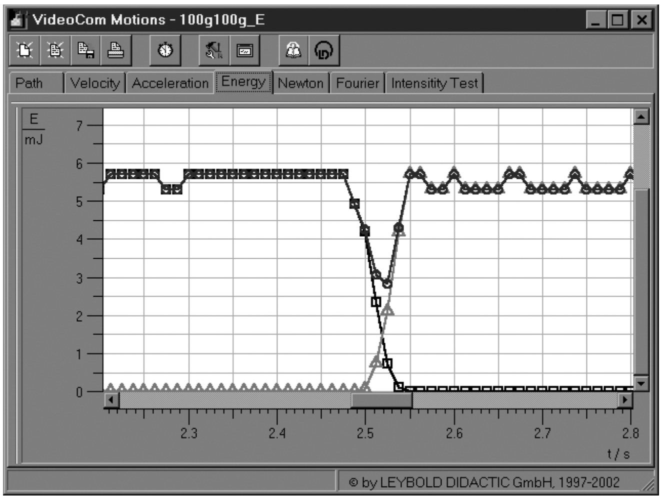

Fig. 5 Kinetic energy-time-diagram for m_1 = 100 g, m_2 = 100 g (□ : 1, △ : er 2, ○ : both gliders).

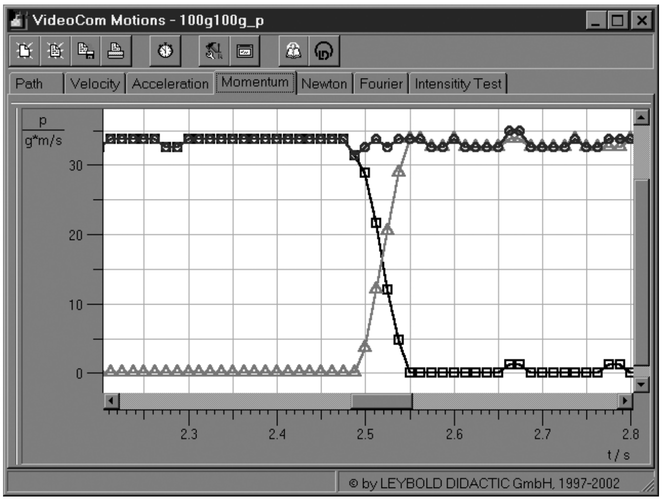

Fig. 6 Momentum-time diagram for m_1 = 100 g, m_2 = 100 g (□ : glider 1, △ : glider 2, ○ : both gliders).

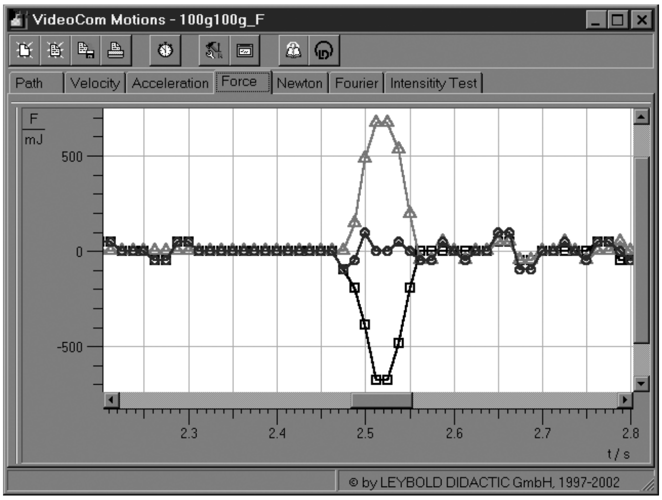

Fig. 7 Interaction force-time-diagramm for m_1 = 100 g, m_2 = 100 g (□ : glider 1, △ : glider 2, ○ : both gliders).

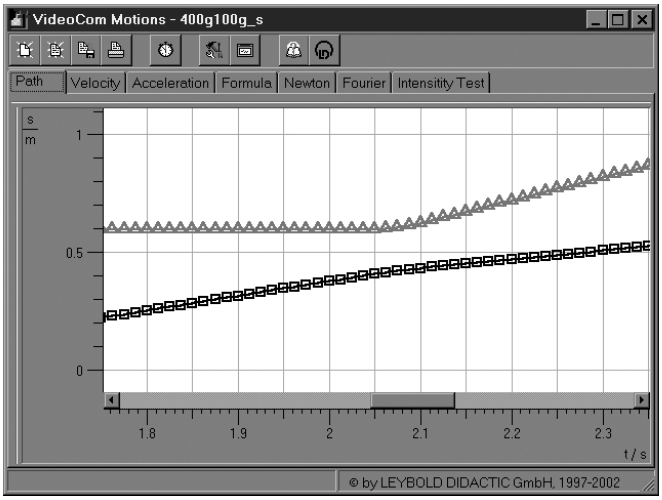

Fig. 8 Path-time diagram for m_1 = 400 g, m_2 = 100 g
(□ : glider 1, △ : glider 2).

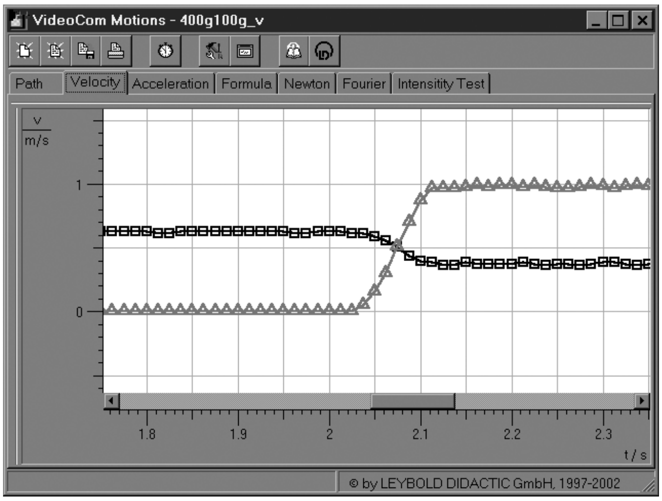

Fig. 9 Velocity-time diagram for m_1 = 400 g, m_2 = 100 g
(□ : glider 1, △ : glider 2).

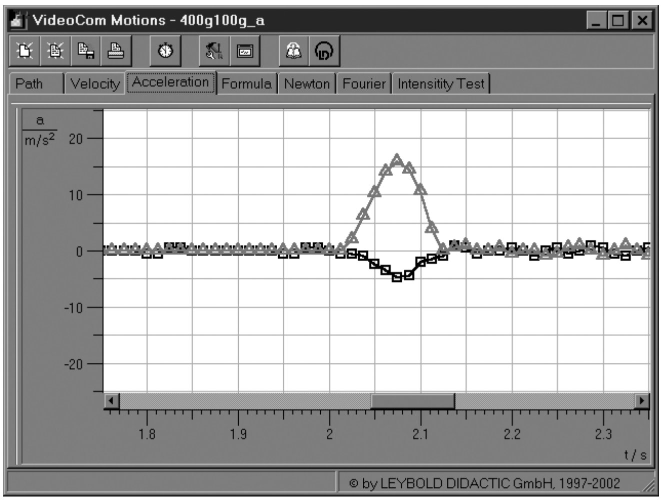

Fig. 10 Acceleration-time diagram for m_1 = 400 g, m_2 = 100 g
(□ : glider 1, △ : glider 2).

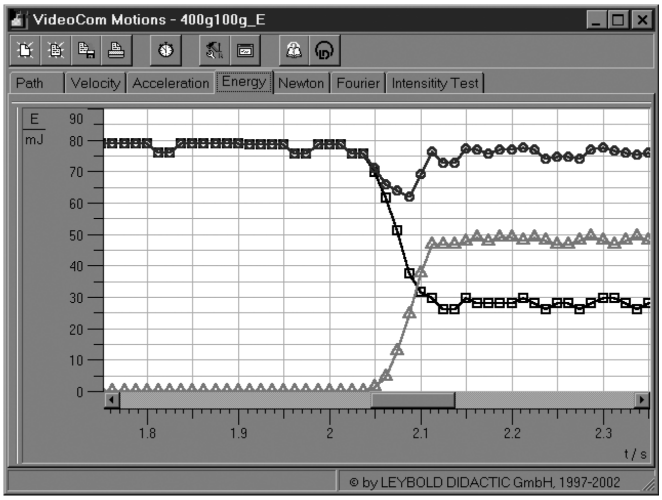

Fig. 11 Kinetic energy-time diagram for m_1 = 400 g, m_2 = 100 g
(□ : glider 1, △ : glider 2, ○ : both gliders).

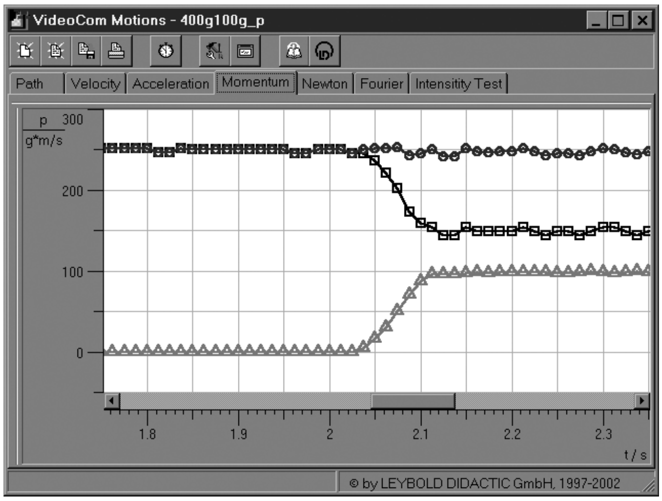

Fig. 12 Momentum-time diagramm for m_1 = 400 g, m_2 = 100 g
(□ : glider 1, △ : glider 2, ○ : both gliders).

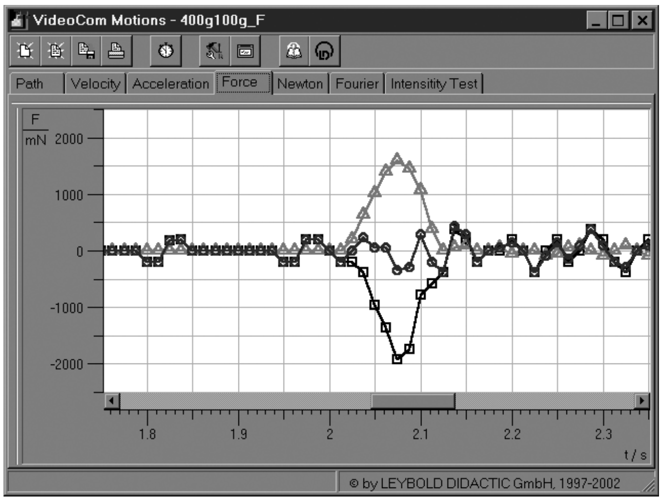

Fig. 13 Interaction force-time diagramm for m_1 = 400 g, m_2 = 100 g
(□ : glider 1, △ : glider 2, ○ : both gliders).

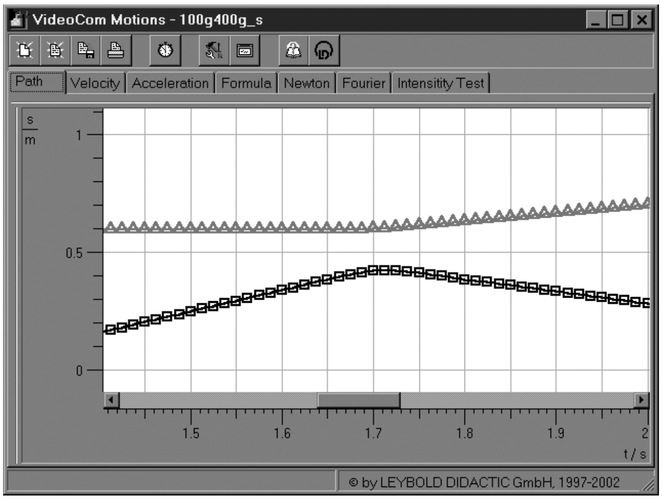

Fig. 14 Path-time diagramm for m_1 = 100 g, m_2 = 400 g (□ : glider 1, △ : glider 2).

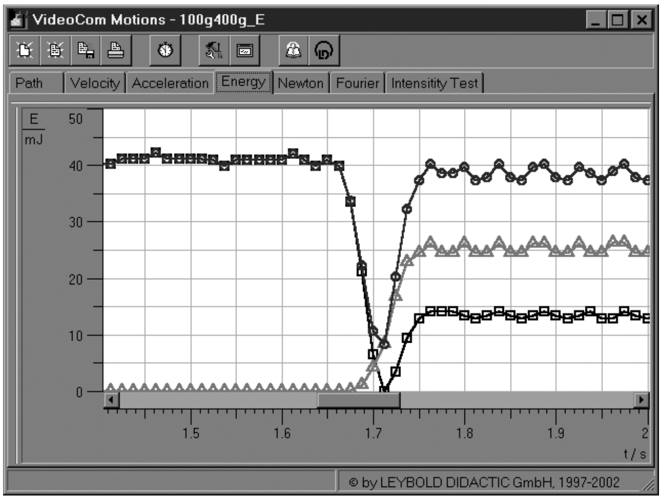

Fig. 17 Kinetic energy-time diagram for m_1 = 100 g, m_2 = 400 g (□ : glider 1, △ : glider 2, ○ : both gliders).

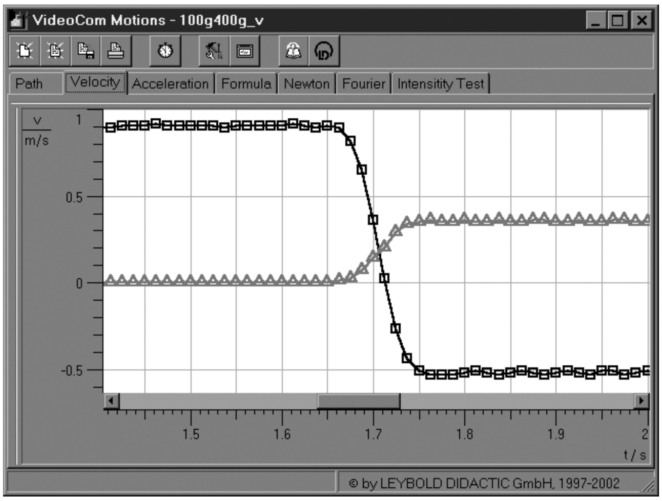

Fig. 15 Velocity-time diagram for m_1 = 100 g, m_2 = 400 g (□ : glider 1, △ : glider 2).

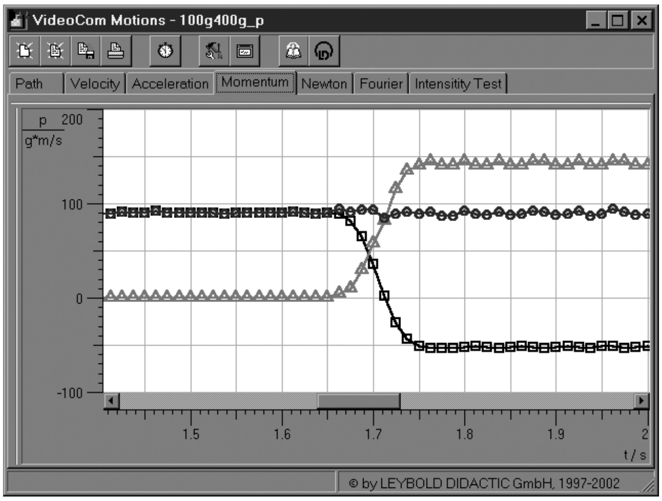

Fig. 18 Momentum-time diagram for m_1 = 100 g, m_2 = 400 g (□ : glider 1, △ : glider 2, ○ : both gliders).

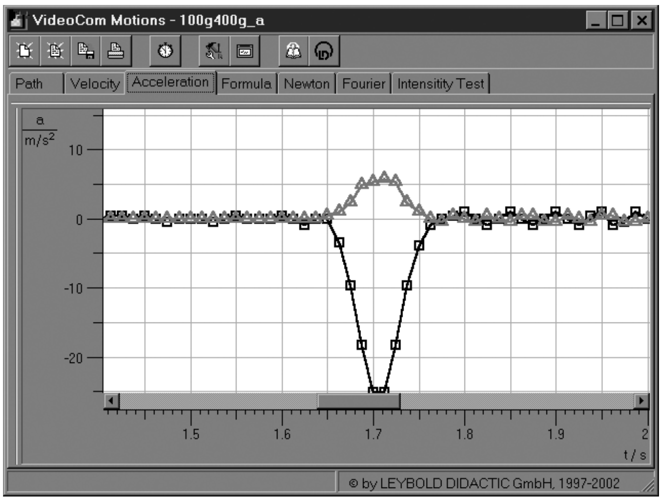

Fig. 16 Acceleration-time diagramm for m_1 = 100 g, m_2 = 400 g (□ : glider 1, △ : glider 2).

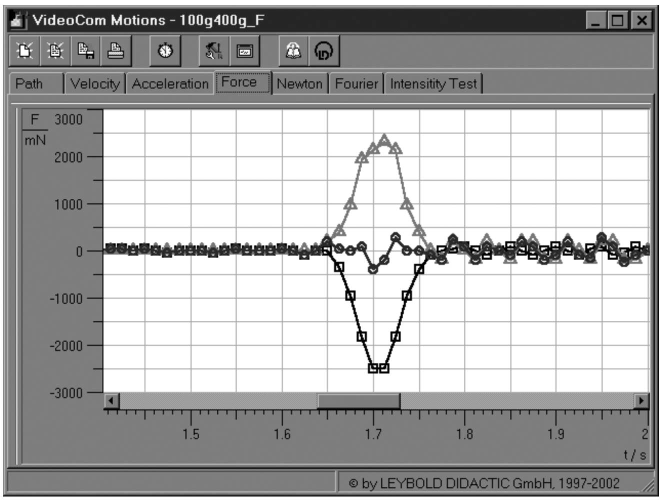

Fig. 19 Interaction force-time dagramm for m_1 = 100 g, m_2 = 400 g (□ : force on glider 1, △ : force on glider 2, ○ : both gliders).

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