THEORETICAL INVESTIGATION OF THE DYNAMIC BEHAVIOR OF AN INSTRUMENT PLATFORM FOR THE OBSERVATION AND MANIPULATION OF A FREE FALLING SAMPLE INSIDE A DROP TUBE

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Abstract

Extensive weightlessness experiments can be carried out in a laboratory, although at a limited duration, with a drop tube and a proper equipment.
The sample will be dropped exclusively. For transfering data from and to the sample during the fall it is accompanied by an instrument platform (IP) which is guided inside of the tube and controlled by a motor/pulley/belt drive.
The differences of distance, velocity and acceleration between sample and IP must approach zero in a relatively short time.
Also, at the bottom of the drop tube, the IP with a mass of about 4 kg must be decelerated softly, in order to avoid damage on sensitive instruments, and carried back to the starting position subsequently. So, it can be used for another dropping. The sample with a mass of about 10 g will be caught seperately.
This paper deals with a computer simulation using ACSL*) which results in essential information for the construction of a demonstrator and a 30 m drop tube which is planed in a further stage. Also, the operational aspect is discussed in this paper.

*) Advanced Continuous Simulation Language

Introduction

A drop tube facility is frequently used for weightlessness experiments and containerless processing in the field of materials science.
It is a vacuum apparatus existing of three chambers which are seperated by valves. On the top, there is the bell jar with the sample positioning-, heating-, release system, etc.. In the middle the drop tube where solidification of the sample occurs and at the bottom the catch chamber (see Figure 1).
The sample has a diameter in the range 2-10 mm and the duration of the fall depends essentially on the height of the drop tube and whether the tube is evacuated or gas flooded. Detailed investigations about physical influences on drop samples have been carried out e. g. at the Fachhochschule Aachen [1].

Since the sample travels with increasing velocity inside the tube, it is a challenging task for robotic application e. g. to measure the temperature time profile or to carry out some manipulation. The author was engaged with this matter at TBE in Huntsville, Ala. and at ZARM in Bremen [2,3].

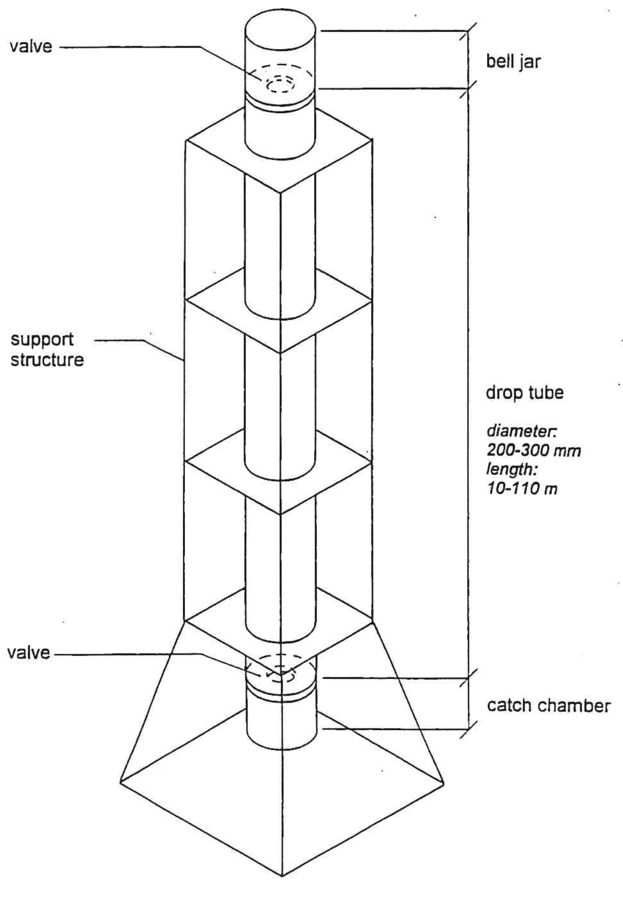

Figure 1: Basic construction of a drop tube facility.

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System Description

The mechanical construction of the motor/pulley/belt drive is shown in Figure 2.
Instrument platform and weight, it is supposed to tighten the wire which are used for transmitting data from and to the sample, are guided on two rails.
Since one end of the wire is fixed to the IP and the other end to the middle part of the drop tube, the weight travels with half of the distances, velocities and accelerations of the IP. It is assumed that the maximum acceleration of the IP is below $1.5g_0$ and the resistance force affecting the weight (e. g. friction and aerodynamic drag) is below $g_0 m_{weight}/4$.
With regard to the braking requirements, the IP is driven by two motors resp. two synchronized velocity servos.

The piloting and control concept of the IP -drive mechanism is illustrated in Figure 3.
Since the start position of the IP is below the sample, an executive routine (A) generates the command values for the start sequence when the released sample actuates the start sensor S1. In this way, sample and IP will approach each other smoothly.
As soon as the sample meets the IP, switch 2 will be actuated and the command values comes from now on from the falling sample itself (measured by two position sensors fixed on the IP) or from a computer (E) which calculates the trajectory of the sample in realtime.
The deceleration and the reset of the IP- drive mechanism is managed by an executive routine (C).

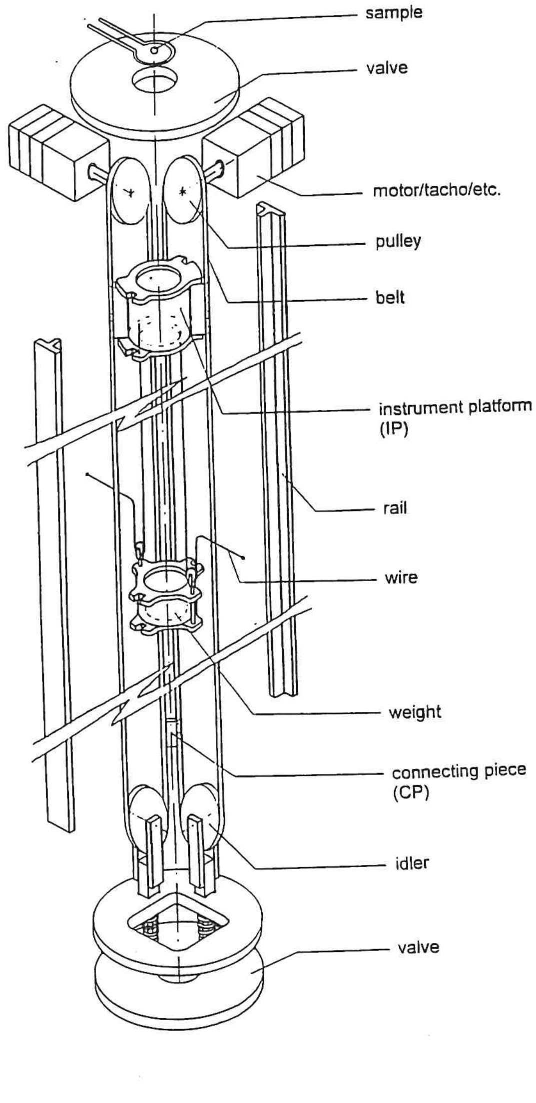
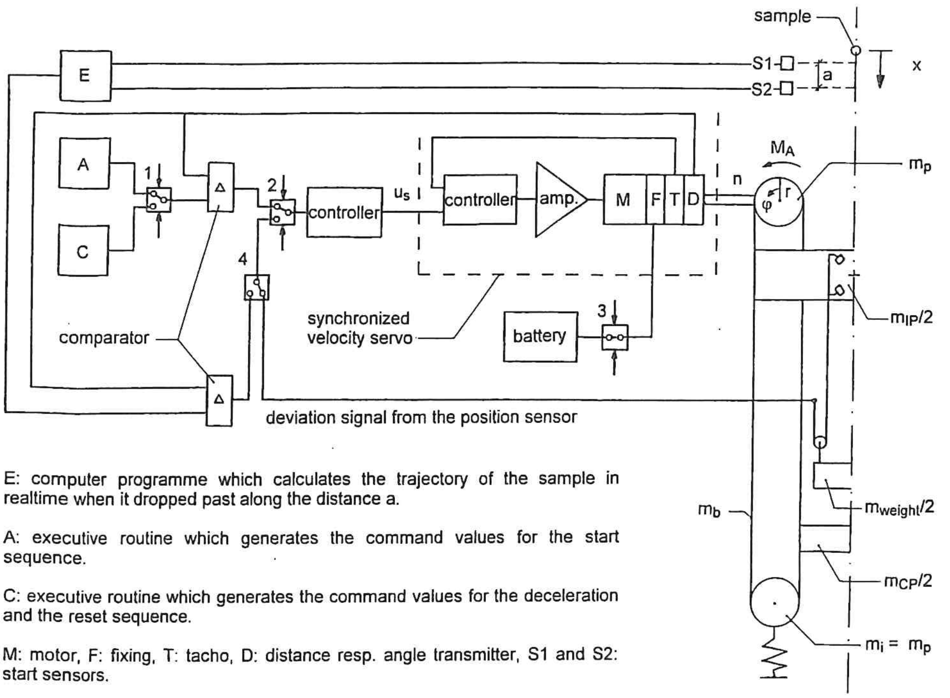


Figure 2: Arrangement of the IP- drive mechanism inside the drop tube (the motors are mounted outside on flansches and the rotary transmission is sealed by vacuum feedthroughs).



E: computer programme which calculates the trajectory of the sample in realtime when it dropped past along the distance a.

A: executive routine which generates the command values for the start sequence.

C: executive routine which generates the command values for the deceleration and the reset sequence.

M: motor, F: fixing, T: tacho, D: distance resp. angle transmitter, S1 and S2: start sensors.

Figure 3: Piloting and control concept of the IP- drive mechanism.

Figure 4 shows the mathematical model which was used for the computer simulation.
A $PI I_2$- controller was selected and the transfer function of the velocity servo is assumed to be constant. I.e. the rotational speed is strictly proportional to the signal voltage and not affected by the load.
This can be achieved with a standard velocity servo since the speed and the load is in a certain range.

In Table 1, the essential parameters of the simulation are shown.
The drop tube is evacuated. Therefore, the trajectory of the sample is given by the law of falling ($0.5 g_0 t^2$) as it is illustrated in Figure 5 together with the command positions of the IP and the weight. Note that the weigth travels with half of the distances which is visualized in Figure 2.

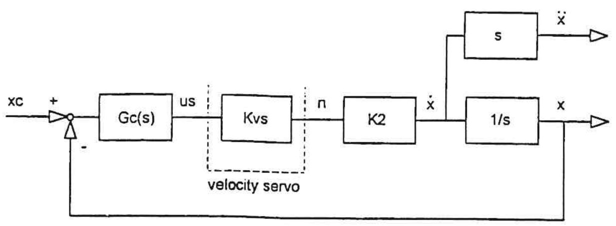


Figure 4: Mathematical model which was used for the computer simulation.

mass of inertia*) $\ddot{x} > 0 / \ddot{x} < 0$	4.55 [kg] / 4.675 [kg]
radius of the pulley	0.065 [m]
initial error	0.4 [m]
stoping distance	4 [m]
drop height	30 [m]
auxiliary factors Kvs / K2	400 [1/Vmin] / 0.0068 [m]
control parameters Kp1 / Ki / K3	30 / 460 / 1260

*) calculated for one motor

Table 1: Essential parameters of the simulation.

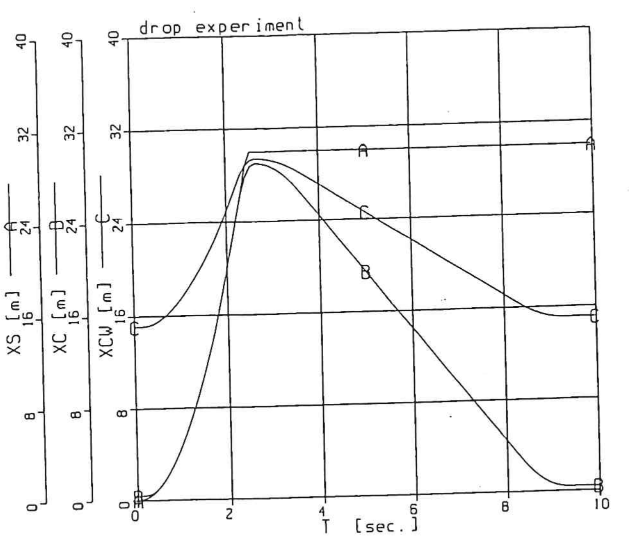


Figure 5: Trajectory of the sample and command positions of the IP and the weight.

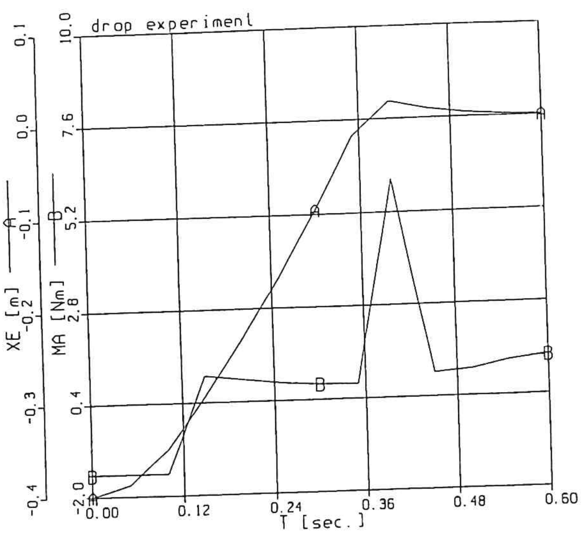


Figure 7: Errors (distances between sample and IP) and driving torques.

Results and Discussion

The start sequence of the drop experiment is illustrated in Figure 6 and Figure 7.
As soon as the released sample actuates the start sensor S1, the IP starts moving downwards with about $0.75g_0$.
It takes 0.4 seconds before the sample meets the IP and about 0.5 seconds till the error is compensated.
The driving torques are well within the capability of standard velocity servos and the maximum acceleration is below $1.5g_0$ (i.e. the two wires are kept thightened).

The braking of the IP- drive mechanism occures after 2.3 seconds which is illustrated in Figure 8 and Figure 9.
The driving torques and the rotational speeds are in the range of standard velocity servos and since the belt is tightened, there won't be a belt slippage (i.e. no additional brake is necessarry, which might be fixed in the lower part of the drop tube).

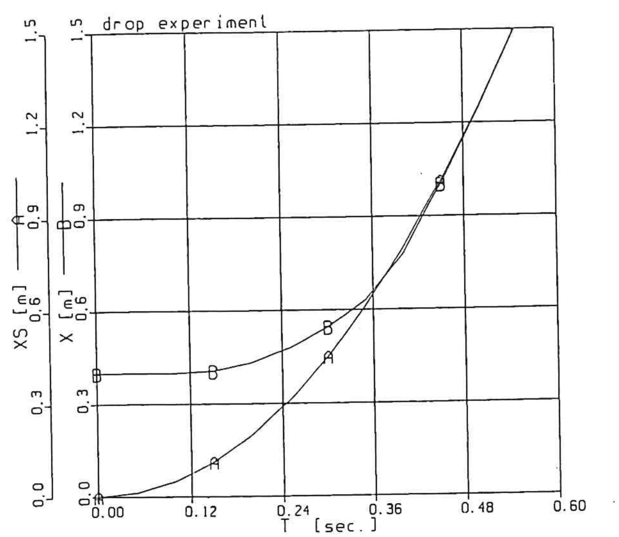


Figure 6: Trajectory of the sample and real positions of the IP.

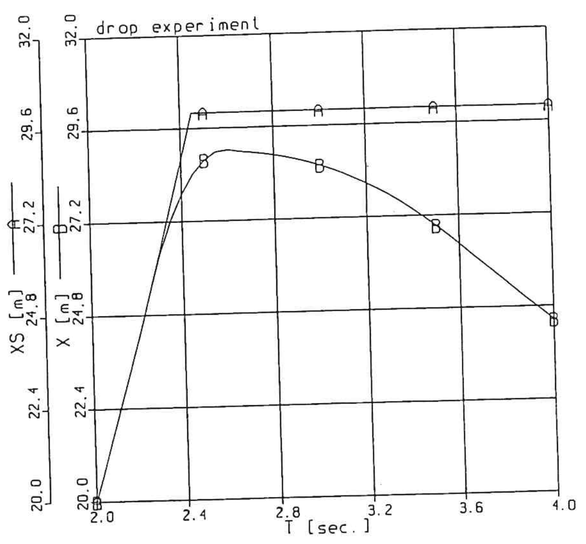


Figure 8: Trajectory of the sample and real positions of the IP.

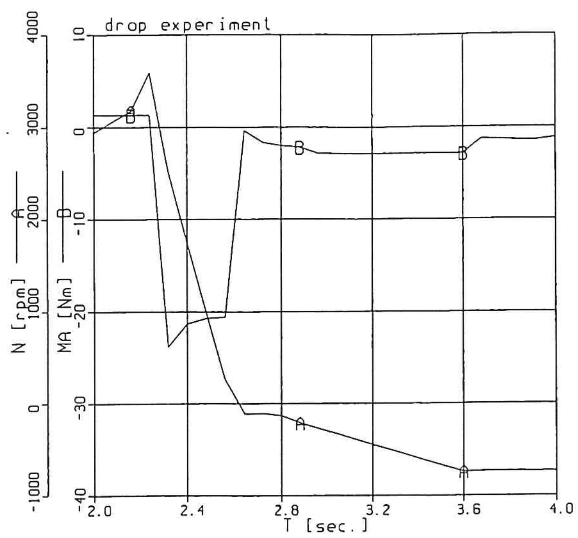


Figure 9: Rotational speeds and driving torques.

Now, the effective time where the falling sample and the IP are together is about 2 seconds. This means that e. g. the solidification of the sample should be placed within this time window.
Since the simulation has shown that this drive mechanism works well (of course, easy assumptions were made), the final implementation of the control system has to be tested experimentally with a demonstrator [4].

Conclusion

A drop tube with this equipment would be perfectly suitable for materials scientific research institutes and universities.
On the instrument platform, a camera and a manipulator, a pyrometer or any other detectors could be mounted and it actually allows scientists to carry out some experimental works in a microgravity environment.
Of course, the experiment time is limited since it depends on the height of the drop tube. But how the past has shown, it is still enough time to get some useful results [5-8].
In any case, drop tubes represent the most accessible and lowest cost alternative for containerless reduced-gravity experimentation and it might be paying to improve the possibilties of transfering data from and to the sample during the free fall [9].

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Nomenclature

g_0	[m/s^2]	acceleration of gravity
m_{weight}	[kg]	mass of the weight
M_A	[Nm]	driving torque
n	[rpm]	rotational speed
xc	[m]	command position of the IP
x	[m]	real position of the IP
us	[V]	signal voltage
xs	[m]	position of the sample
xcw	[m]	command position of the weight (14.9 m + xc/2)
xe	[m]	distance between sample and IP (xs - x)

IP: instrument platform, CP: connecting piece

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