DEVELOPMENT AND QUALIFICATION OF A SAMPLE TRANSLATION SYSTEM FOR A FLUID SCIENCE EXPERIMENT IN THE INTERNATIONAL SPACE STATION

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ABSTRACT/RESUME

The presented mechanism belongs to the FASES (Fundamental Applied Study of Emulsion) Experiment, project for the micro-gravity program FSL (Fluid Science Laboratory).
The STS (Sample Translation System) mechanism is developed by MECANEX in collaboration with HTS, responsible for the development of the FASES Experimental Container. An Engineering Model (EM) has been manufactured and is in its testing program.
The STS function is to translate 44 individual liquid containing samples and present them sequentially to two separate instruments. The very narrow available space allowed by the Experiment Container (EC) and the constraints imposed by the two investigation instruments lead to a configuration where the samples are translated along a guided path by increments of one sample at a time.
The concept selection, design and manufacturing were subject to high time pressure, what enhanced the challenging nature of the project for the engineer and production team.

1. INTRODUCTION

Emulsion phase transitions is studied in the FASES experiment. The stability of various compositions of droplets dispersed in suspension are investigated with a calorimeter and a microscope.
The preparation requires an in situ processing of the samples which compositions are pre-defined and loaded in 2 types of liquid tight sample holders.
The experiment is implemented in a standard container of overall dimensions 400 x 280 x 270 mm^3 and includes:

- microscope
- calorimeter
- thermal control devices
- sample processing device
- drive electronics
- 44 samples
- sample transfer mechanisms to the processing and investigation instruments
- sample storage and selection mechanism

The last three functions belong to the Sample Transfer System (STS).
The available space allocated to the sample transfers devices and the 44 samples storage measures only 288 x 241 x 88 mm^3. An independent addressing of each sample must be possible and a sample identification device is also required. This device should be able to identify unambiguously the analyzed samples even after a complete loss of power.
The sample transfer mechanisms must also be able to apply a load of 20 N when in an instrument working position. The heat leak from the sample to the mechanism needs to be minimized (< 5E-4 W/K), and the maximum allowed electrical power is limited to 5.5W with a limited number of channels that can be run in parallel. The maximum mass allocated to the STS is 6 kg.
The experiment will be flown on the International Space Station and must be compatible with the Columbus Pressurized Payload requirements as well as the launch environment of alternative carriers: MPLM, ATV and Soyuz Transport Vehicles environment constraints.

2. DESIGN TRADE STUDIES

The main challenge for the STS design was essentially driven by the very scarce available volume. Very little conceptual solutions survived this constraint.
The following concepts were investigated:
Sample storage:

- on an array
- on a rotating drum
- on a rotating mat
- in silos
- on tracks and carriages
- in guided queue

Sample transfer mechanisms:

- robotic arm
- telescopic devices
- pushers
- linear screw translators
- pneumatic and hydraulic translators

- cable and chain translators
- rack and pinion translators

The solutions involving excessive height (> 88 mm) had to be abandoned due to the size of the instruments and optical path defined by the microscope.
Rotating drums could have been an interesting solution; however none could accommodate the 36 samples initially specified as minimum number, as for the track and carriage solutions.

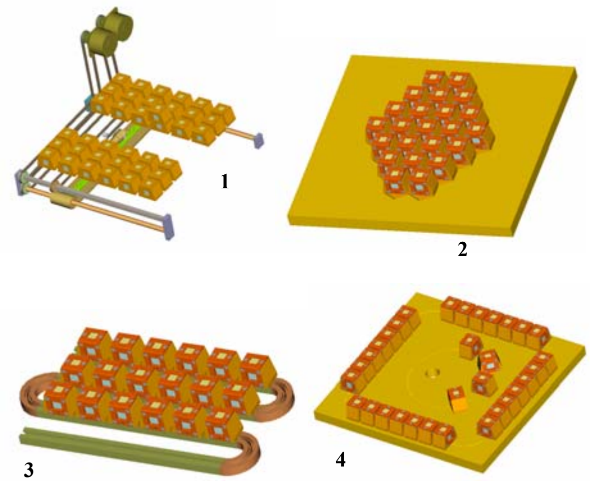

Figure 1: Various storage concepts
1: Array and belt transport
2: Array and robotic arm
3: Samples on track
4: Circular arrangement

The array arrangement of the samples would have been the most attractive as many samples can be gathered on a small surface, and this concept implies parallel addressing, i.e. a minimum access time to any sample. The space availability constraints forced however a chain solution implying a sequential access to the samples.

3. SELECTED DESIGN DESCRIPTION

Figure **2** sketches the selected design.
Forty-four samples are disposed in orthogonal grooves in a base plate; an upper cover also confines the samples, leaving only one translation degree of freedom. Linear actuators are placed at each corner. When moved alternately along X and Y directions, a general translation of all the samples pushing each other is obtained.

The translation drives each sample sequentially under the position of the two instruments (Differential Scanning Calorimeter (DSC) and microscope observation area, the thermal control unit (TCU)). The translation of about 90 mm from the sample storing position to the instruments is assured by

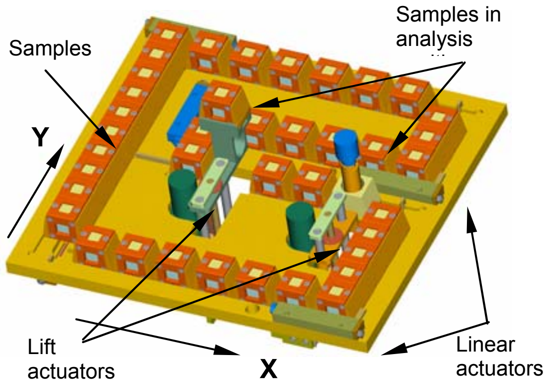

Figure 2: Selected design principle

two lifts (Figure 3) actuated by screws and DC motors and gearboxes. Some interface adaptations are necessary to accommodate the different sample types dedicated to DSC and TCU. The general design is however identical.

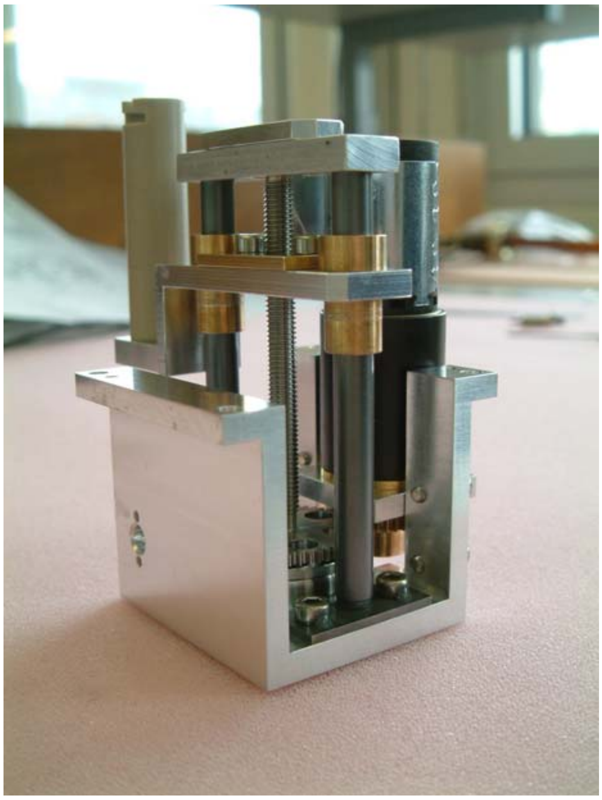

Figure 3: Lift mechanism

The X and Y linear sample translation actuators are simple pushers with a spring defining the pusher (Figure 5) to a stable position when the driving force is relaxed. The driving force is applied by a DC linear motor and gearbox rotating a pulley around which steel

cables are wound. The force is conveyed to the actuator pushers (Figure 5) by a flexible lubricated tube as represented by Figure 4. Four cables for each direction are necessary. The movement is automatically synchronised with this concept.
The movement of the pulley is limited by mechanical stops and end switches control the motor movement and direction.

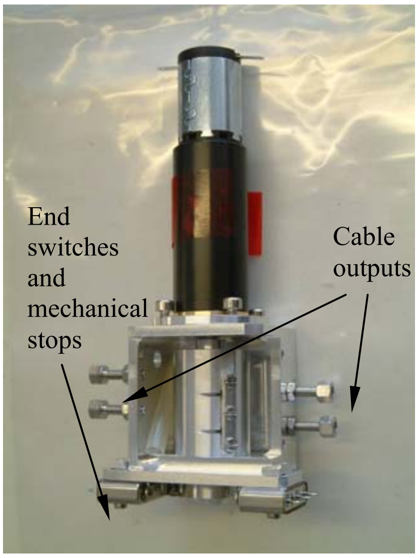

Figure 4: X and Y translation actuator system

The cable tension in the tubes is set with screws so that backlash free operation is achieved.

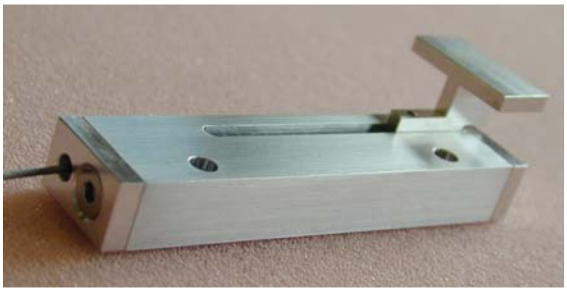

Figure 5: X and Y actuator pushers

The design is modular so that each sub-assembly can be mounted and checked independently prior to integration on the Base-Plate
Figure 6 shows the top view of the Base-Plate without samples and cover. The Lifts, pushers and guiding grooves for the samples are well visible.
The view of Figure 6 and Figure 7 were taken during Engineering Model integration. The surface treatments are not applied according to the final definition (see § 5 below).

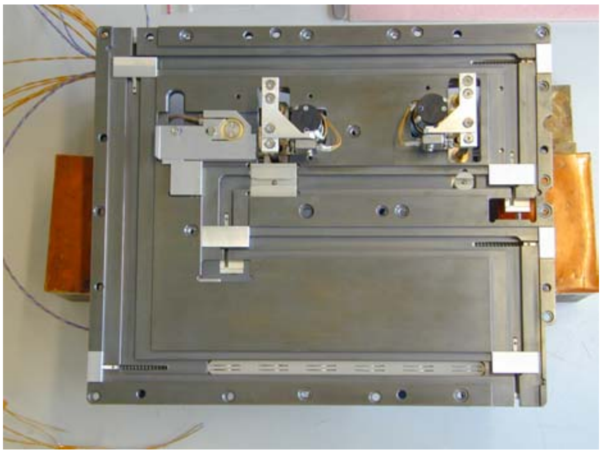

Figure 6: Assembled Base-Plate (top view)

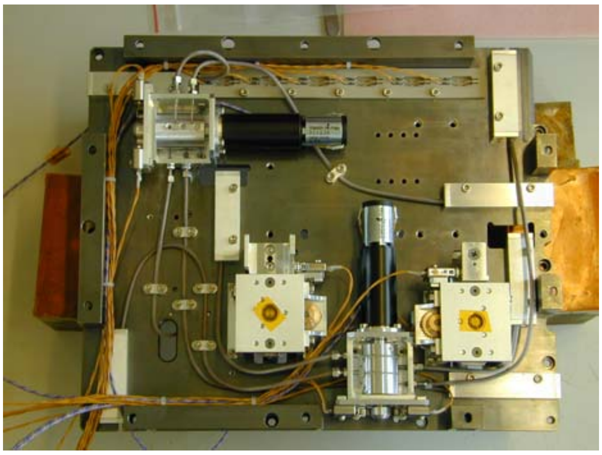

Figure 7: Assembled Base-Plate (Rear view)

4. SAMPLE IDENTIFICATION SYSTEM

The requirement of sample identification at any time, even after complete loss of the electric power had to be solved with a very rugged and simple device. Various concepts were studied:

- Bar chart and optical reading
- 6 bits digital coding attached on each sample and read by electrical contact
- Resistors attached to each sample and read by electrical contact
- Several types of proximity sensors
- 1 bit digital coding attached on each sample and read by electrical contact

The trade-off between these various approaches put forward two main aspects that could be critical with respect to reading reliability:

- Position accuracy of the samples: the samples require some clearance in order to slip with low friction. Sophisticated electric or proximity reading could be affected by the existing backlash.
- Electric contacts may evolve with time. Analogue electric reading could be disturbed by contact degradation.

The bar chart and optical reading would not be affected by the above considerations and could be a suitable candidate for the sample identification. The much more elementary and rugged device based on a single bit attached to each sample and with an ON / OFF simple contact reading has been preferred due to its higher reliability and high redundancy content.

The principle of the coding is based on two basic rules:

- The sample sequence cannot be modified after loading in the chain. When the samples are displaced in the instrument positions, mechanical stops prevent any possible sample order modification.
- The bit sequence attached on each of the 44 samples defines a 44 bit word that should comply with the properties when read by shifted groups of 6 bits:
    - o Any group of 6 bits is different
    - o The sequence is cyclic

These conditions have been demonstrated to exist, and are not unique. A valid sequence is provided on Figure **9** as an example.

The full sample identification can be obtained with only one bit reading at a time. Six consecutive sample translations are thus necessary with only one contact.
In the present application, the choice to implement 6 reading switches in parallel allows to define the sample without sample movement.
However, this option provides a 6-fold redundancy in case of switch failure.
The bit information attached to each sample is made with the help of a metallic or insulating wafer attached on a prominent and accessible feature of the sample and read by a line of spring contacts as illustrated by Figure 8.

Figure 8: sample identification reading switches

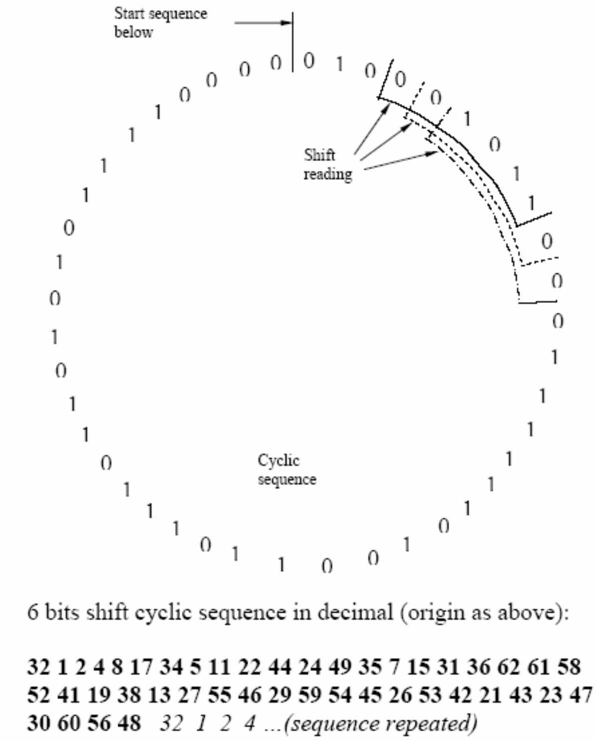

Figure 9: Example of cyclic 6 bit shift sequence

5. DESIGN CRITICAL AREAS

Friction is an important aspect to be considered with this design:

- Samples slip on guiding grooves
- Friction of cables in guiding tubes
- Pushers oriented by slipping cylinders
- Lifts guided with plain bushes

The lubrication is an essential ingredient for the success of this mechanism.
The base plate and metallic parts in contact with moving samples are not submitted to high friction loads. The DICRONITE DL-5 [1] coating appears to be well adapted here with its low friction coefficient (< 0.1), high resistance (Hertz pressure resistance up to 2.2 GPa) and high stability under vacuum and temperature.
The upper guide associated to the cover is made of PTFE used as friction element and damper in vibration.
The cables need lubrication to reduce the friction and constraints. The selected lubricant is a vacuum compatible grease.
A development life test was made to verify the wear conditions and measure the forces to be expected.

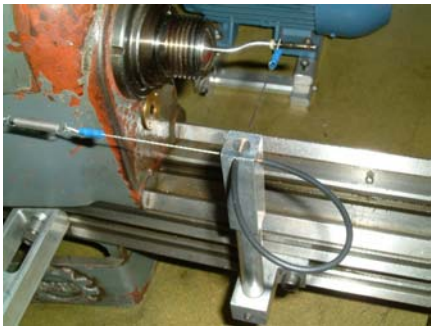

Figure 10: Guided cable life test

Figure 10 is a photograph showing the test setup composed of a cable with 270° deflection and connected to a spring load ranging from 2 to 4 N. The displacement of 30 mm was comparable with that encountered in the mechanism.
The measured friction was < 0.15 over 500'000 cycles. The test was stopped after 1'160'000 cycles without failure. The friction coefficient had risen to 0.26 at this time. This life was considered to be sufficient with respect to the specified 1500 sample measurement cycles.
The pushers have been coated with Ni-PTFE [2] and lubricated with grease. The preliminary tests showed that friction was too important to allow safe operation without appropriate lubrication.
Ni-PTFE is an electro-less coating with a friction coefficient < 0.1; it can be applied easily on the parts, even hollow and has an excellent mechanical resistance for Hertz pressures lower than 600 MPa. It is recommended to apply the coating on both friction members.
The guiding bushes for the lifts are made of bronze slipping on DICRONITE DL-5 [1] lubricated stainless steel. The alignment tolerances and clearances must be carefully respected, but the friction coefficient lower than 0.1 assures that jamming condition is never met.
The second critical aspect area related to this mechanism is related to the guidance grooves accuracy. It is important that the sharp edges of the samples cannot bump in the groove angle. The design should prevent any possible rotation of the sample during its transfer. For this reason, the pusher shapes have been made parallel to the displacement and wide to lock any movement of the samples placed laterally. The groove and sample tolerances need also care: too mush clearance would lead to jamming, insufficient clearance would increase friction.
The width and length sample accuracy needs also to match the piling condition; up to 8 samples in length and 10 in width must be accommodated in grooves of fixed dimensions.

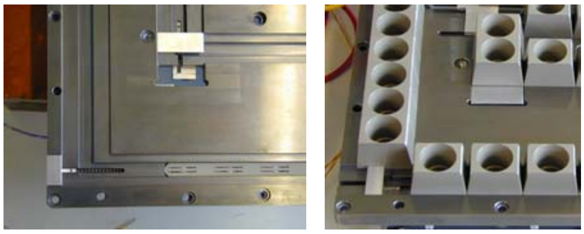

Figure 11: Sample storage groove (detail of a corner without and with dummy samples)

6. TESTING

The STS EM has been mounted in the FASES container and functionally tested prior to vibration.
Many cycles of sample transfers in the storage volume and towards the instruments were made successfully on the EM. The secret of the good functioning of the mechanism resides in fine tuning of the assembled parts (spring forces, tolerances, material and friction control, alignments, etc.).
Though some minor shock marks were observed after vibration, the material was considered acceptable for further functional testing. The results were not known at the moment this article was produced.

7. CONCLUSION

The STS mechanism is a very challenging design work conditioned by a very limited volume and complex sample transfer functions. The innovative nature of the concept is a key factor for the success of this mechanism.
A concept based on the confinement of the samples in a track where each element pushes its predecessor has been proposed.
The translation movements of the stored samples are generated by DC motors and the forces conveyed by slip cables in bent tubes. The transfer of samples from the storage position t the investigating instruments are assured by DC motors, gearboxes and screws.
The main critical areas reside in overcoming friction by suitable lubrication, and in fitting adequately the dimensions of the STS and samples so that no jamming or excessive friction occurs.

8. REFERENCES

1. DICRONITE dry lubricant (DOD-L-85645 Typ 1) Dicronite U.T.E.Pohl GmbH, D-58644 Iserlohn dicronite.pohl@gmx.de
2. Ni-PTFE: Chemical Nickel coating with PTFE inclusion, Steiger S.A. 1800 Vevey, Switzerland steiger@steiger.ch