Innovative Hydraulic Cylinder Concept for Cold Regions with a Piston from Frozen Water

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Abstract

A method to create sustainable support for general assemblies under arctic conditions is presented in this paper. A plunger cylinder is used to generate an ice piston out of frozen water using a repeating sequence of heating, raising and cooling. Laboratory testing by means of a physical model has been performed. Providing new insights in this area of research, the results are presented in terms of feasibility and controllability.

KEYWORDS: hydraulic cylinder, cold regions, ice piston, foundation

1. Introduction

Research facilities in polar regions often cannot be mounted on solid ground and must be designed to built on snow and ice.

Consequently, due to the ductile and thus insubstantial properties of ice and further snowfalls, such facilities will subside into their former foundation and eventually be lost for usage. Solutions, such as lifting the facility by means of hydraulic systems and extending its foundation with snow or new iron stilt segments require continuous and large physical as well as financial efforts. Furthermore, those methods imply the danger of pollution of such sensitive environment.

Additionally, the Protocol on Environmental Protection to the Antarctic Treaty requires environmental assessment for all activities. The so called Madrid Protocol demands all contracting parties to protect the environment, and to remove all remnants or residues from the Antarctica.

Figure 1: Polar station „Neumayer III“ /1/ (left) and polar station „Kohnen” /2/ (right)

Facing this issue and with respect to environmental sustainability, this research study favours a new attempt. In 2007 while working on the foundation of the polar station Neumayer III, the idea of using ice as stilt element for buildings in arctic regions was born.

This technology uses freezing water to generate an ice piston in a hydraulic cylinder itself.

2. Fundamental procedure

Piston extension requires a repetitive stepwise process during which a new segment of ice is created and continuously attached to elongate the piston. This process can be differentiated into the following steps (see **Figure 2**):

2.1. Heating

While heating the cylinder, the outermost layer of the piston begins to melt. The water inflow pipe is extricated from any ice obstruction by pipe heat tracing.

2.2. Raising

Injecting liquid water from the top of the cylinder causes the piston to extend. The injected waters pressure must be high enough to compensate all acting forces (friction and weight-forces in the first place) in order to cause lifting.

2.3. Cooling

Finally, the injected water returns to ambient temperature and freezes. Additional lifting can be observed while the waters condition of aggregation changes to ice.

The entire solidification completes this segment and the extension process can be started over again.

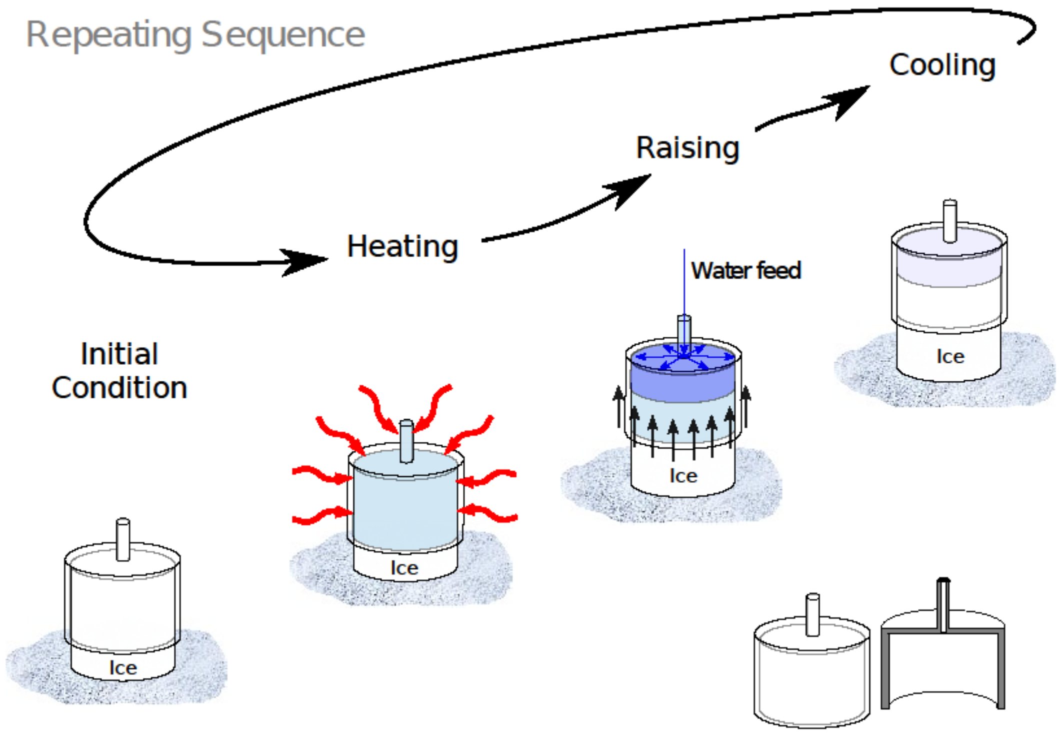

Figure 2: Fundamental procedure

3. Laboratory studies

The following studies were carried out within the scope of an investigation of the realiseabilitiy and applicability of a foundation based on this technology.

Laboratory testing has been performed at the facilities of IgH GmbH in Essen, Germany. It was vital to use a physical model in order to further investigate possible effects, which initially have not been taken into consideration. Focus of this research, however was to investigate whether it is possible to use such a system as basis of polar research facilities or not.

3.1. Experimental model

For the studies, a simple model which was easy to manufacture and easy to modify was designed. The experimental model cylinder was dimensioned to fit into a freezer. To ensure a straight growth, a linear guide was attached (see **Figure 3**). The model cylinder was composed of an aluminium alloy and had an inner diameter of 110 mm and an inner height of 70 mm.

3.2. Tests in a freezer

To simulate arctic surroundings all tests were performed in a freezer at -30°C to -20°C. The water used was tap water, with a pressure of about 6 bar and a temperature around 15°C. It was feeded using a flexible pneumatic pipe.

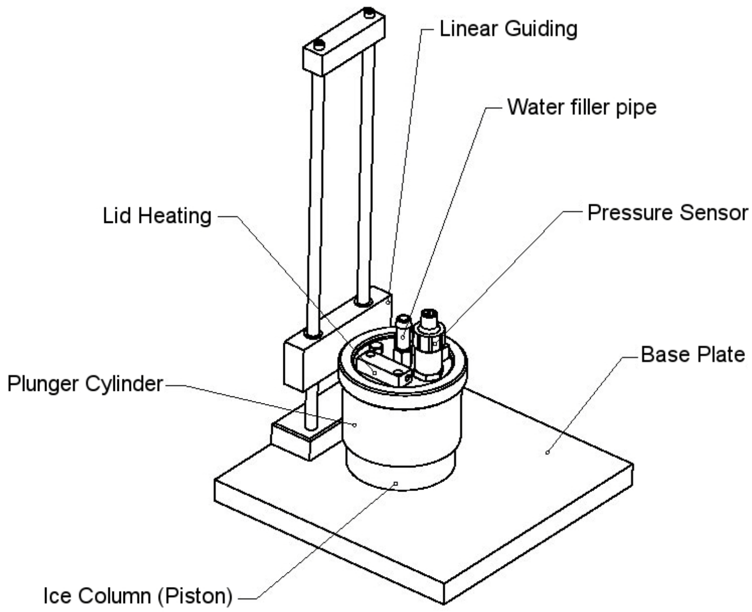

Figure 3: Test assembly

3.2.1. General function

To display the feasabillity of the concept with the model system, the first tests were performed manually. Pressure was applied with a hand operated pump and the heating was done using a hot-air gun.

After a few attempts it was possible to lift the cylinder system with tap pressure. It was difficult not to overheat the cylinder, so that the inflowing water could not flow out of the cylinder side.

It was necessary to defrost the inflow tube completely, so that water could be forced into the cylinder. Additionally, the ice directly surrounding the inflow had to be molten as well.

To gain better controllability the test rig was modified, so it could be operated and monitored from a computer terminal completely.

The following changes were made:

- a solenoid valve was inserted into the water feed
- an electrical lid and pipe heating was installed
- a wire cable sensor to measure the vertical cylinder position was added
- a pressure transducer for the water pressure was installed
- two temperature sensors to measure the lid and freezer temperatures were added
- a webcam and light was installed in the freezer so the freezer could stay closed

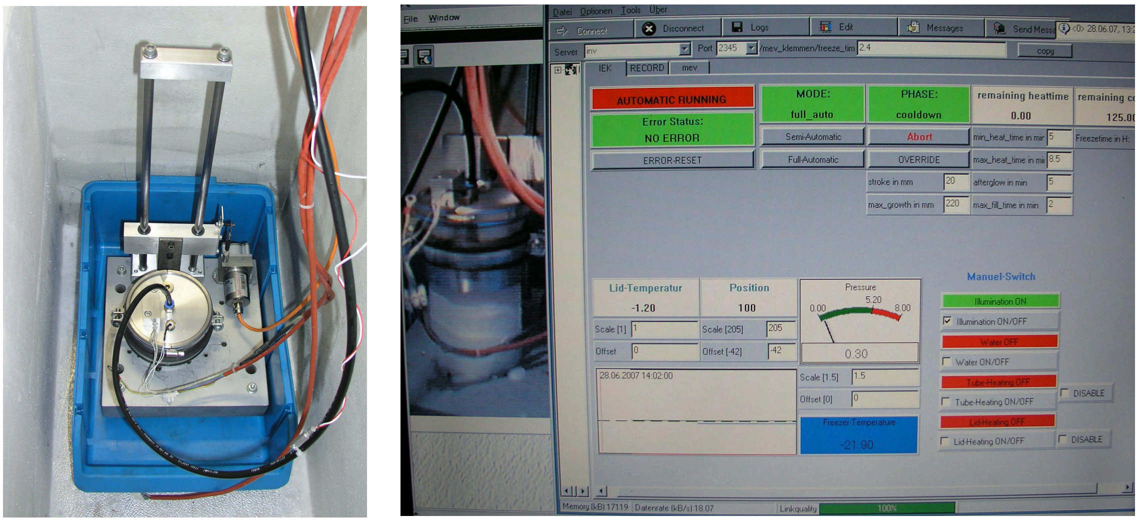

Figure 4: Model system (left) and control GUI (right)

Further testing was realized by operating the modified test set-up via a computer interface (see **Figure 4**).

The behavior was analyzed and a method generating an ice piston was found empirically. The prevailing influence on the system's behavior had the following parameters:

- the stroke, corresponding the amount of water feeded
- the heating times for tube and lid
- the freezing time

3.2.2. Automatic growing

In the next step, it was attempted to transcribe the manually determined sequence into an automatic control program. All previously analyzed parameters and the general sequence were embedded in this control program, and could be modified at run time. The program even considered some failure cases, like a leakage at the cylinder wall, reacting with an adapted behavior.

Due to a missing valve to the environment, the initial bleeding of the cylinder still had to be done by hand.

After a few adjustments, the system was able to generate an ice piston in fully automatically. During a twelve hour run, a 220 mm long piston was generated with single strokes of 20 mm as shown in **Figure 5**.

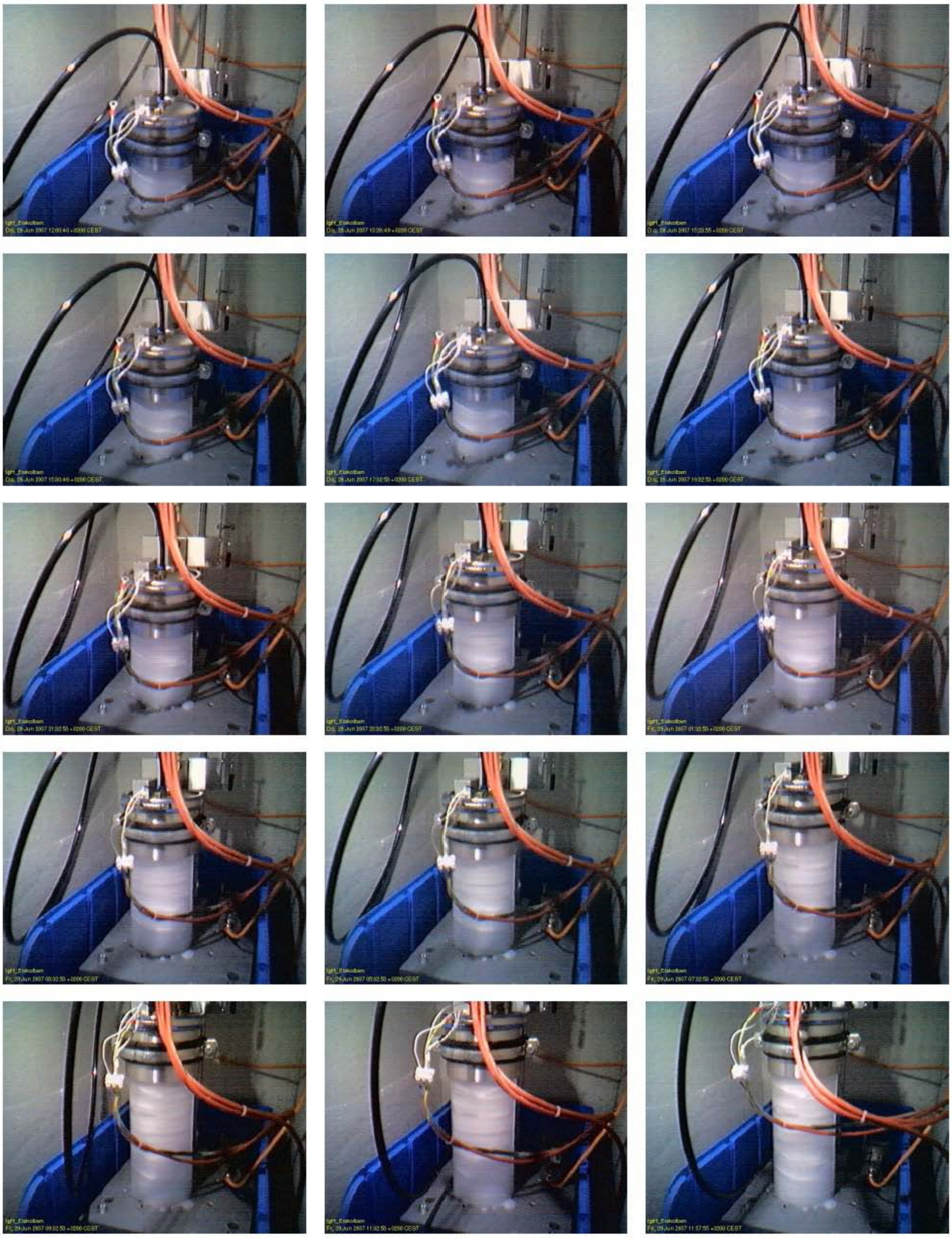

Figure 5: Fully automated process to generate a 200 mm piston using 20 mm strokes

3.2.3. Growing under load

To examine the usability of the technology and to simulate a load, the cylinder was stressed with different load magnitudes. The counter force was applied by the help of a hydraulic cylinder which was placed over the ice cylinder pushing it down.

To change the load, an adjustable relieve pressure valve was used (see **Figure 6**).

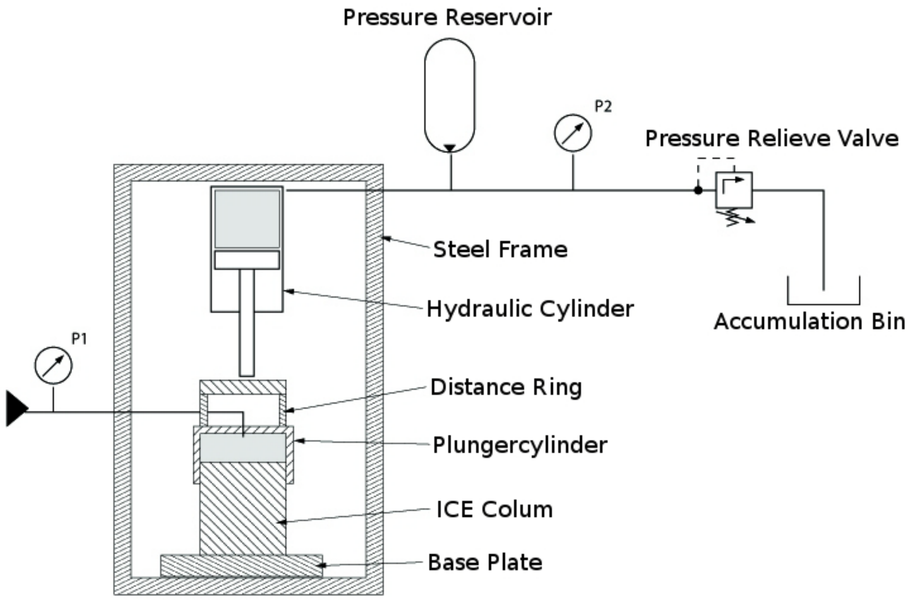

Figure 6: Static load simulation

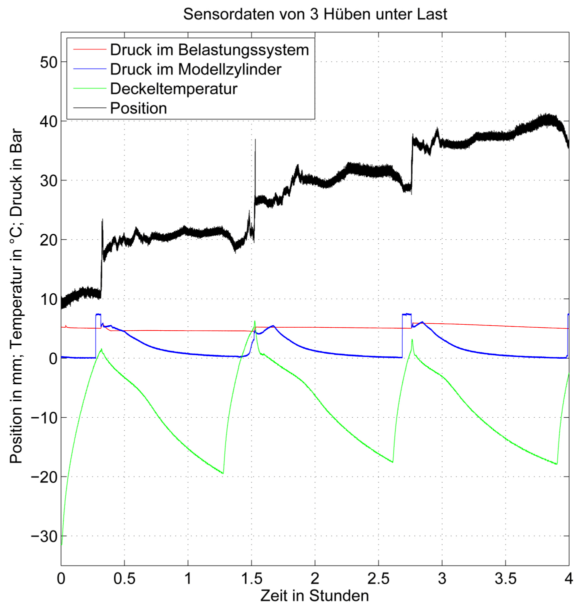

Figure 7: Model system for load simulation (left) and three strokes with load (right)

In order to prevent commonly appearing leakages, the stroke had to be reduced involving an extension of the sealing length. The system was able to extend against a simulated constant load of 4 kN (0.42 MPa) in full automatic operation. **Figure 7** shows the actual test assembly.

3.3. Piston load capacity tests

In order to rate the load capacity of an ice piston some pistons were tested for their compressability. To this purpose they were mounted in a test assembly as shown in **Figure 8**.

Different load scenarios were tested, including maximum load capacity and behavior under a load over a extended period of time.

A force transducer was used to record the applied compression forces. The load to the specimen was applied slowly using a hand operated hydraulic pump. The ice pistons were able to sustain loads of up to 10 bar (10^6 N/m^2) over a longer period of time. A structural failure of the pistons could be observed at load magnitudes between 25 bar and 40 bar (25 MN/m^2…40 MN/m^2).

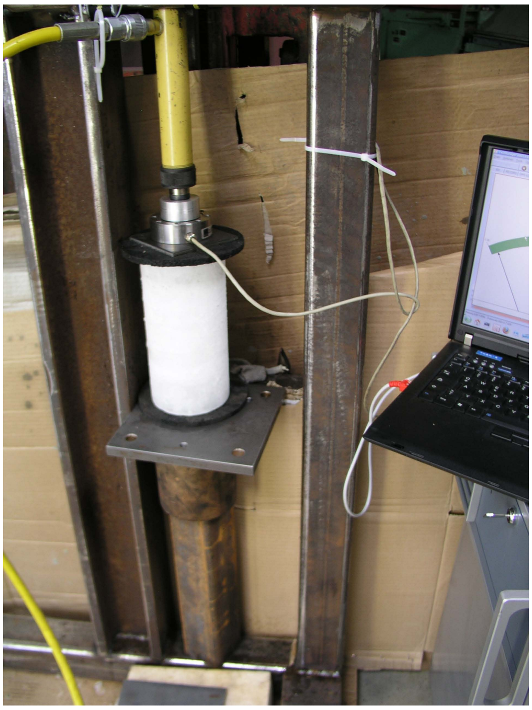

Figure 8: Compression testing

4. Summary

The studies showed that a cylinder operating using this procedure is technically feasible, and controllable. In addition it showed that an operation of the cylinder under load and even in automatic controlled applications is possible.

The research results allow the assumption that this technology is qualified as a basis for arctic regions.

While however some studies could not be performed in a necessary or preferable complexity a more detailed and profounded research is planned as a cooperation between IgH and the Alfred Wegener Institute. With the objective to test a full-scale prototype in Antarctica, this multi-stage research campaign will begin early in 2012.

5. References

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