Institut für Baustatik und Konstruktion ETH-Zürich

pressure-friction compensation model

# Force calculation of hydraulic cylinders with pressure-friction compensation

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# Kapitel 1

# Usage

## 1.1 Initial position

Hydraulic cylinders are used in many experimental tests for loading test blocks. Often pressure sensors are used to measure the chamber pressure conditions for calculating the loading force.
The friction behaviour of a hydraulic cylinder does depend on different factors [1]. This document describes a calibration routine to compensate the friction influences. Therefore tests were made where multiple cylinders were loaded in an universal testing machine. The process was done by machine first and afterwards the cylinders were actuated by a handpump where a seperate daq-system measured the force of the universal testing machine and the pressure in the chambers.

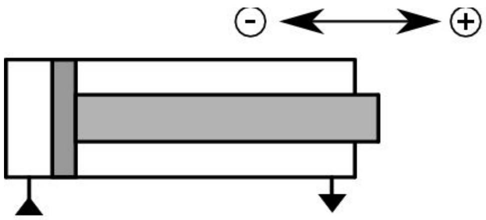


Abbildung 1.1: hydraulic jack

### 1.1.1 Calibration process

The cylinder is loaded in three cycles from $F_{start}$ to $F_{top}$. This is shown in figure 1.2 The upper graph shows the forces-time diagram, which is the forced measured from the machine $F_m$ and the force calculated over pressure by $F_p = p * A_{nominal} = pressure * cylinderareanominal$.
Next the differenz between $F_m$ and $F_p$ is shown.
And the last graph shows the derivation of the machines position $w'_m$which gives the moving direction.

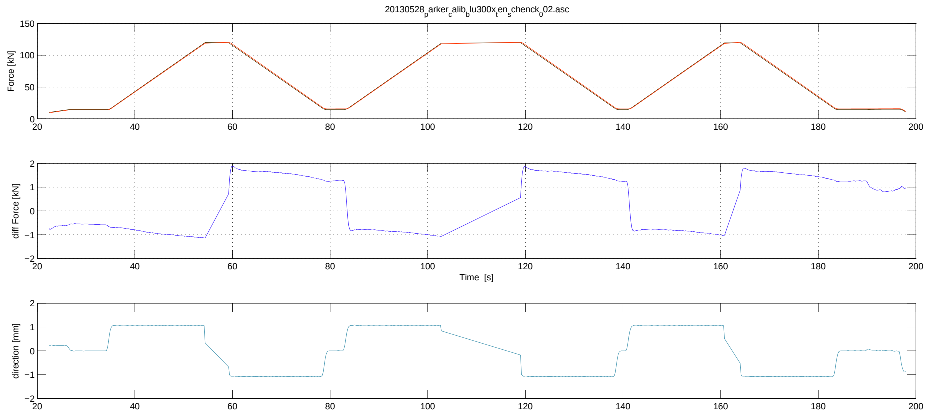


Abbildung 1.2: loading curves

Taking a range of abour 90% in between $F_{top} - F_{start}$ a linear behaviour is expected. Plotting the data on a x/y-graph, where x is the hydraulic pressure and y is the measured force the following graph is produced:

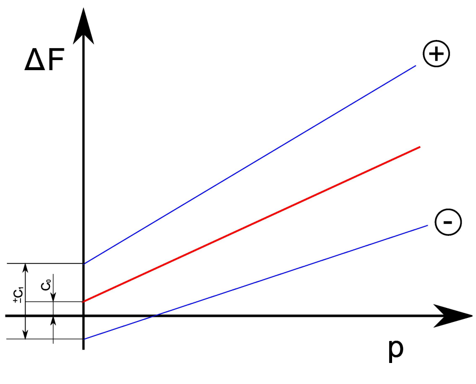


Abbildung 1.3: Force-pressure graph

The shown curves shows different factors influencing the pressure to force characteristics. First there is an offset of the pressure signal to the force signal. Then there is a proportional deviation of both signals and last the moving direction of the piston influences the relation between pressure and force.

## 1.2 Friction model

Looking at figure 1.3 and the described influences the following mathematical model can approximate the behaviour between pressure and force. It must be mentioned that the offset $c_0$ is expected to be a sensor offset between the load-cell and the pressure sensor and therefore can be neglected.

$$F = p \cdot A \cdot f_1 \pm (c_1 + f_2 \cdot A \cdot p) \tag{1.1}$$

$F$ = Force
$p$ = pressure
$A$ = nominal piston area (can be diffrent in tension/pressure direction)
$c_1$ = friction offset
$f_1$ = piston area factor
$f_2$ = direction factor

**Friction offset** $c_1$ The friction offset $c_1$ depends on the moving direction of the cylinder. This is probably caused by a stip/slick effect, which can also be an effect of moving catridge seals.

**Piston area factor** $f_1$ A piston area factor can be derived out of calibration measurements to correct the applied piston area. There can be deviations caused by inaccuracies from manufacturing. Also friction characteristics can cause changes in the applied piston area.

**Direction factor** $f_2$ This factor corrects the hysteresis effect when acting direction changes. There can be unequal friction behaviours for positive and negative moving directions.

Beside the ïnternalëffects of the cylinders which influence the force-pressure relation also the used pump, hoses, tubes, valves and the oil itself can vary these factors. It is always recommended to do the calibration tests with the same equipment which will later be used in the experiment.

## 1.3 Empirical values

Calibration data was acquired by several tests with different cylinders.

After analysing this data the **Piston area factor** was up to $(100 \pm 0.5)\%$.
And the same scale was analysed for the **direction factor** $\pm$ 0.5%.
Both factors are larger than the possible measurement resolution, why the findings of this document should be considered when measuring forces by pressure.

## 1.4 Prospects

For further researches analysing the following influences could enhance the models value.
Tribology which can change mechanical characteristics will change the factors. This stipulates the calibration of the cylinders in periodically.
Only some experiments were made where the dynamic of the test velocity varied. This could be studied in additional tests.
Certainly the oil characteristics influences the model, as also other hydraulic elements (valves, tubes...) will.
Temperature will change the behaviour of oil and the cylinders, which could be analysed in future research projects.

# Literaturverzeichnis

[1] Xuan Bo Tran, Nur Hafizan, Hideki Yanada. Modeling of dynamic friction behaviors of hydraulic cylinders. http://www.google.ch/url?sa=t&rct=j&q=hydraulic%20cylinder%20friction%20behaviour&source=web&cd=4&cad=rja&ved=0CEcQFjAD&url=http%3A%2F%2Fwww.rmcet.com%2Flib%2FE-Journals%2FMechatronics%2FVolume%252022%2C%2520Issue%25201%2C%2520Pages%25201-136%2520(February%25202012)%2F1-s2.0-S0957415811001954-main.pdf&ei=5SXxUdOSBrOp7Abpr4HYCg&usg=AFQjCNGTQtUTObaaGJ8t3CBxXbHsK_O3lA&bvm=bv.49784469,d.ZGU, 2012.