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Experimental Measurements on a Stand for a Grain Sampler

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This paper describes experimental measurements of travel rollers on a polyurethane thread. This experiment took place at the CTU Faculty of Mechanical Engineering in the laboratory of the Department of Design and Machine Parts. The experiment was performed within the project of a lightweight type of sampler, designed by a team of collaborators from our institute for OK Servis BioPro, s.r.o. For the newly designed type of sampler, it was necessary to determine the operation of a newly designed grain sampler. The load of the rollers is different in each environment. This paper presents the average values from the measurement, including its evaluation. Moreover, the paper compares different temperatures that can be achieved in the practice. Negative temperature values were not performed, as this measurement would be expensive and inefficient.

Keywords: grain sampler, experiment, measurement, travel roll, polyurethane

1 Introduction

The agriculture and food production is facing increased economical and ecological pressure in order to improve its efficiency and reduce the waste in the whole production chain [1]. The motivation for the work presented in this paper comes from design of a new variant of grain sampler to be used for quality evaluation of granular material samples taken directly from trucks or railway carriages, see e.g. [2] or [3] for typical samplers and probes concepts. In the new design the sampling probe is positioned using linear motion mechanisms containing wheels or rollers rolling along the rail.

The rollers tread can be made of different materials, including steel, aluminium, rubber or different polymers or urethanes. For the application in sampler rail carriage, the rollers with urethane tread were chosen. The main reason behind this choice was lower noise generation (compared to fully metallic rollers) during the sampling head carriage motion along the steel rails. But there are also other favourable properties of urethane rollers, including increased corrosion resistance or vibration damping [4]. On the other hand the durability or rolling resistance under high load of urethane rollers doesn't meets the parameters of the full metal rollers. This is mainly due to lower elastic (Young) modulus of urethane versus steel. For comparable loading, the urethane tread deformation is higher than the one of steel for the roller of the same size. This is behind the higher rolling resistance [5] of urethane rollers, but also contributes to their higher wear and reduced durability under high loads and loading cycles [6], [7]. Many useful information in this respect can for example be obtained from American Society for Testing and Materials (ASTM) in their Directory of ASTM Test Methods for Cast Urethane Parts [8] and the standards mentioned there.

Rollers exist in wide range of varieties for different specific applications, sustaining different loads and other operational conditions. The key parameters are namely the diameter and with of the roller tread and of course its material. The choice of rollers for the designed grain sampler was dictated by the size limitations, price and widespread availability of the chosen rollers. This is why finally the roller R 85x50-20 was chosen, having the steel disc (with ball bearing) and urethane tread (diameter 85 mm, width 50 mm) with hardness 95 +/- 5 Sh, resisting temperatures -40 to +60 °C. This roller is primarily designed for hand pallet truck. Therefore producer doesn't provides any detailed information about the roller durability and rolling resistance under different loads and other operating conditions.

In order to be able to guarantee the quality and long-term operability of the final product (grain sampler), it was decided to perform additional experimental verification of the rolling resistance of the chosen roller under various loads and temperature settings. In general the operation and testing of wheels, rollers and casters is formalized in the ISO 22883:2004 - Castors and wheels - Requirements for applications up to 1.1 $m.sec^{-1}$ (4 $km.h^{-1}$) [9] and ISO 22878:2004 Castors and wheels - Test methods and apparatus [10]. Besides of these general purpose regulations, each manufacturer uses its own methods, equipment and norms to design the rollers and verify their parameters [11]. In order to keep the cost of the tests low, while being able to guarantee the results, we have decided to built a new simple test rig to perform the required measurements.

2 Testing

Many different test beds are used for testing the wheels, casters and rollers in various situations for specific purposes. They usually contain some running drum, turntable or belt on which the tested wheel is placed under the pre-specified load. Examples of such testing machines and setups can be found e.g. in. [12], [13], [14], [15] and [16]. From the available test rigs concepts we have opted for the running drum variant, where the roller runs on top of a directly driven drum, while the load is imposed on the wheel by the weight placed on an arm. This rather simple design allows for measurement of the torque and resulting tractive force and the loading force, traction velocity or other operation conditions can easily be set. This device is in principle similar to *Luggage Wheel Wear Test Machine* [17], but has simpler design and was built from standard widely available components and materials. Other ideas dealing with similar issues can be found in [14-20].

3 Experiment

For experimental measurement and verification of the functionality of polyurethane thread travel rollers, a simplified measuring stand was designed and assembled, see Figure 1. This measuring stand is built in the laboratory of the Department of Design and Machine Parts of the Faculty of Mechanical Engineering in Prague.

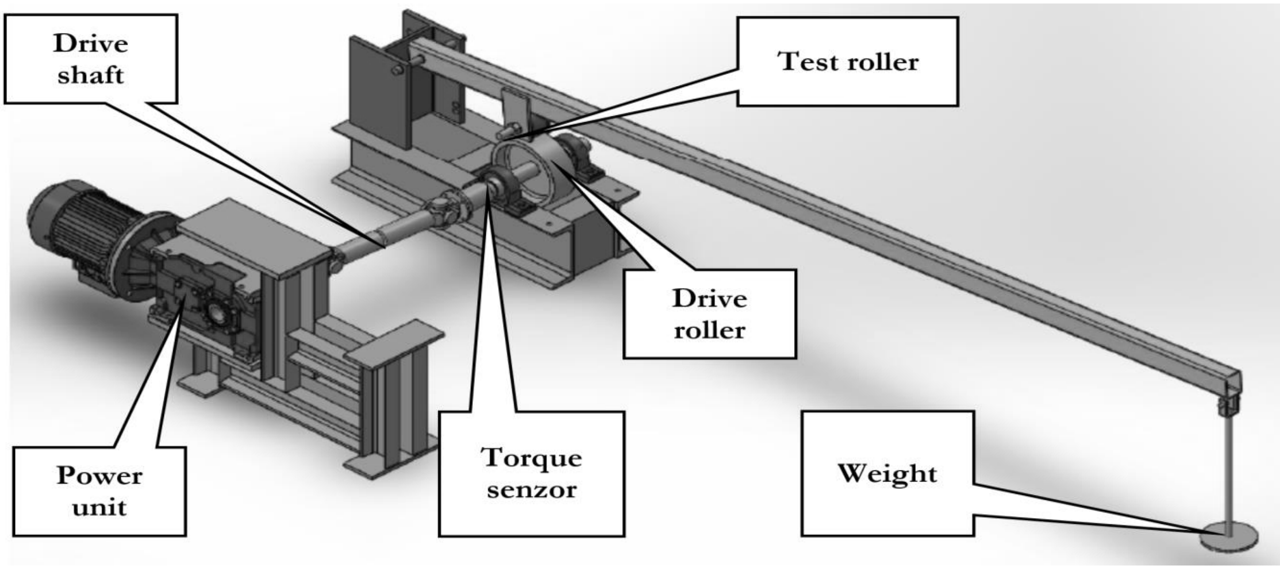


Fig. 1 *Measuring stand model*

It can be seen from Figure 1 that the motor of the 2.2 kW drive unit was connected to a frequency converter. A Kistler 4520A sensor connected to a Dewetron Sirius control panel operating at a basic recording frequency of 20 kHz was used to record the supplied torque, which was reduced in the control and recording SW of the Dewesoft X control panel for measurement purposes. The load was derived by placing the weights on a designated hinge on a beam with a tested roller. Regarding the width of the working surface of the driving roller, rollers with a width of 50 mm with a diameter identical to the diameter of the rollers used in the sampler (85 mm) were purchased for testing.

4 Measurement and data analysis

The measurement was performed in the following phases:

- Verification measurements according to the manufacturer's standardized test of the manufacturer
- Short-term measurement of the effect of load and temperature
- One-day durability test
- Weekly accelerated durability test

4.1 Verification measurements according to the manufacturer's standardized test of the manufacturer

First, it was necessary to make measurements to determine the accuracy of the assembled measuring stand by direct comparison with the data provided by the manufacturer on the tested rollers by means of the relevant data sheets, see Table 1, which contain the following information:

Test conditions:

- 20 ° C
- Smooth flat concrete surface (it was not

possible to determine, here the concrete is provided with some varnish)

- Load derived from the loading test trolley
- Towing speed of the truck 4 km.h^{-1}
- The measured quantity is the tensile force

Tab. 1 *Data from the manufacturer's data sheet*

Load [kg]	Tractive force [N]
300	36
400	50
500	78

Verification measurements were performed according to the test conditions according to the following specification:

- 20 ° C
- Smooth surface of cast iron drive roll
- The load is derived by placing weights on the hinge of the beam of the tested roller
- The measured quantity was applied torque
- The speed of the drive roller was set to 105 1.min^{-1} (this corresponds to approx. 4 km.h^{-1})
- Each load was maintained for five minutes; the resulting value of the applied torque is the arithmetic mean of the values recorded in this interval

The measured values of the supplied torque were converted to the corresponding tensile force on the axis of the tested roller using defining relations. The following simplifying assumptions were made for the conversion:

- The cooperating surfaces of the tested roller and the drive roller are absolutely rigid
- Transfer efficiency is 100%

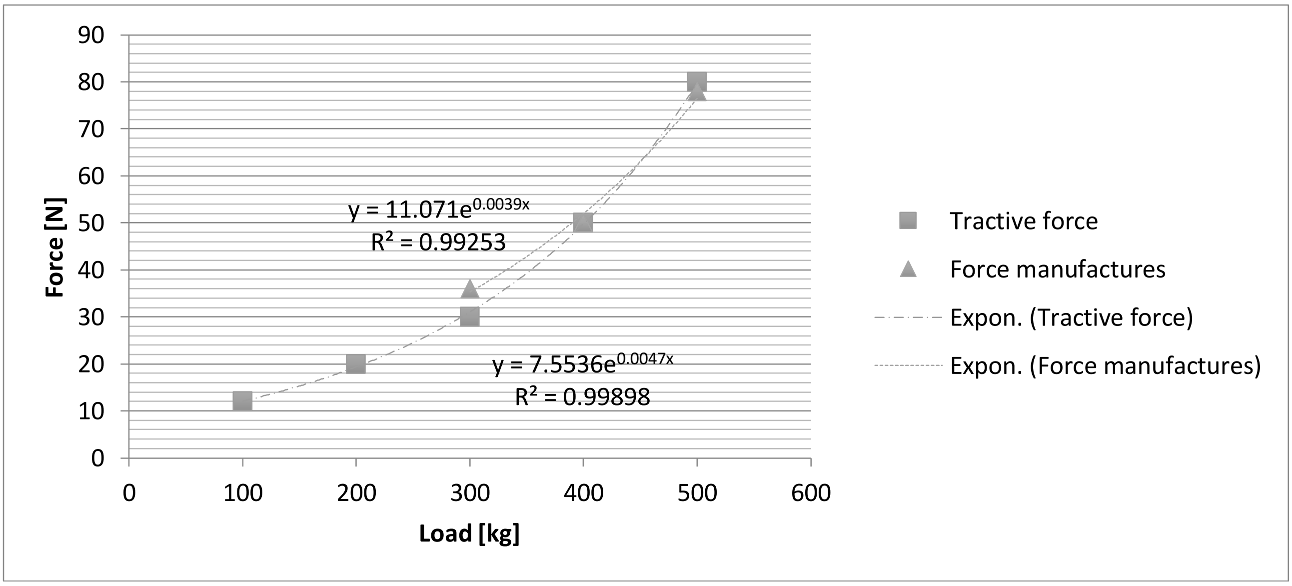
The measured and recalculated data, including data on the corresponding radial force load of the tested roller, are given in Table 2.

Tab. 2 *Measured data*

Load [kg]	Torque measured* [Nm]	Torque on the tested roller [Nm]	Tractive force** [N]
100	2.4	1.02	12
200	4.0	1.70	20
300	6.0	2.55	30
400	10.0	4.25	50
500	16.0	6.80	80

Where:
*…Rounded to one decimal place,
**…Rounded to units.

For better clarity, a comparison of tensile force measurements from the manufacturer's catalog is shown in Graph 1. The individual points are interpolated by an exponential curve, as can be seen in Graph 1. An illustrative idea of the inaccuracy of the method used compared to the manufacturer's data can be obtained from Graph 1. The uncertainty of the measured values expressed by the standard deviation is an order of magnitude lower than the presented values. It can be stated that the set method provides reliable and trusted data.



Graph 1 *Comparison of tensile force measurements from the manufacturer's catalog*

4.2 Short-term measurement of the effect of load and temperature

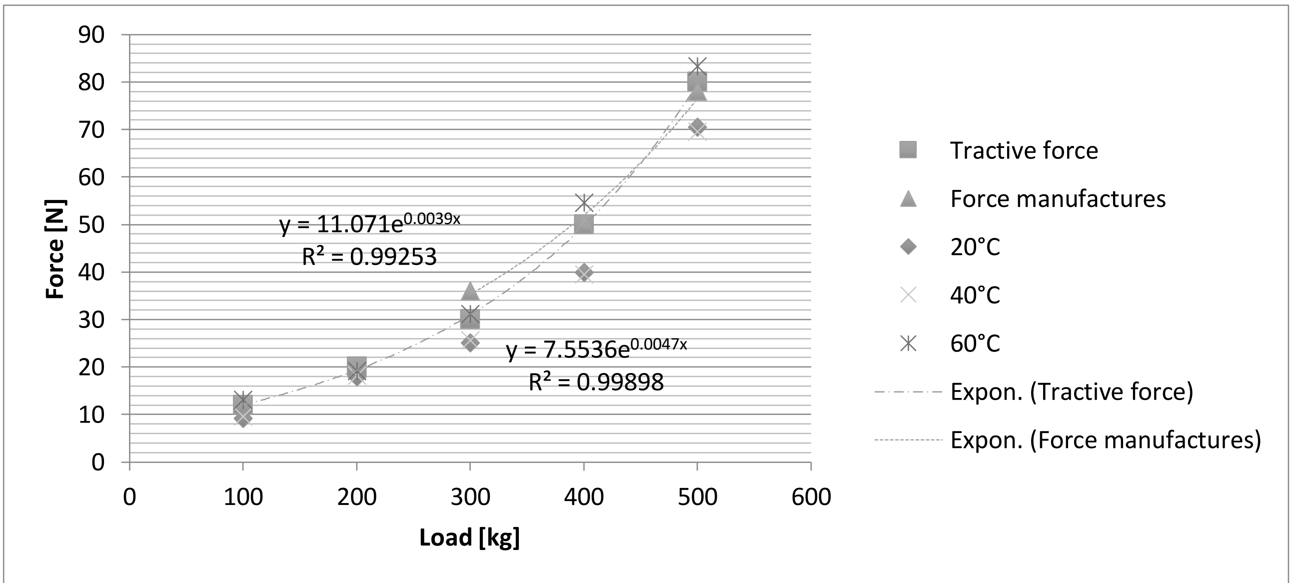
Measurements were performed to determine the effect of the load applied to the tested roller at different temperatures according to the following protocol:

- Tested temperatures: 20 - 60 ° C by 20 ° C
- Tested loads: 100 - 500 kg by 100 kg
- Drive roller speed: 9.5 $1.min^{-1}$ (this corresponds to a peripheral speed of 0.1 $m.s^{-1}$ at which the sampler moves)
- Five minutes was maintained at each temperature for each load; the resulting value of the applied torque is the arithmetic mean of the values recorded in this interval

Tab. 3 *Measured data for short-term measurement of the effect of load and temperature*

	20°C	40°C	60°C	20°C	40°C	60°C	20°C	40°C	60°C
Load [kg]	**Torque measured* [Nm]**			**Torque on the tested roller [Nm]**			**Tractive force** [N]**		
100	1.8	1.9	2.6	0.77	0.82	1.11	9.1	9.5	13.0
200	3.6	3.6	3.8	1.53	1.53	1.62	17.9	18.2	19.1
300	5	5.1	6.2	2.13	2.17	2.64	25.0	25.5	31.1
400	8	7.9	11	3.4	3.36	4.68	39.9	39.4	54.6
500	14	13.8	16.6	5.95	5.87	7.06	70.5	69.5	83.3

Where:
*…Rounding to one decimal place.
The temperature was induced by a hot air gun aimed at the working surface of the drive roll and was monitored by means of an HT18 thermal imager.



Graph 2 *Immediate effect of load and temperature*

An illustrative idea of the impact of different loads at different temperatures can be obtained from Graph 2. It can be seen that up to 40° C the properties of the polyurethane thread of the tested roller do not change, the data overlap. At 60° C, even at a low peripheral speed of 0.1 $m.s^{-1}$, the resistance effect reaches the resistance level for a temperature of 20° C at a peripheral speed of 1.1 $m.s^{-1}$. This fact shows the importance of respecting the expected operating temperatures when dimensioning the pull-out drive units. This may be, together with the fact that the resistive force had to be estimated from the expected load of the rollers in the sampler by extrapolating the data, the reason why the column extension drive unit had to be strengthened.

4.3 One-day durability test

This measurement was performed to determine the stability of the properties of the tested roller for a load of 400 kg at different temperatures during 24 h without a break in the ongoing load according to the following protocol:

- Tested temperatures: 60 ° C
- Tested loads: 400 kg
- Drive roller speed: 9.5 $1.min^{-1}$ (this corresponds to a peripheral speed of 0.1 $m.s^{-1}$ at which the sampler moves)

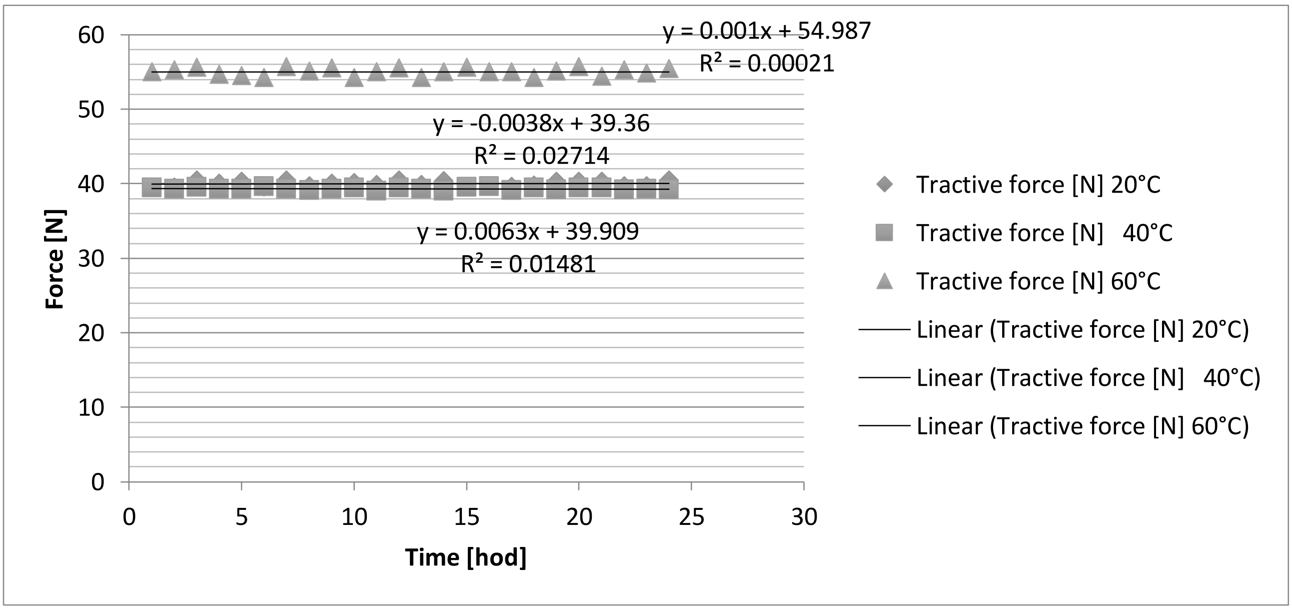
It was maintained at each temperature for 24 h; the load values presented below are arithmetic averages of measurement from the hourly intervals.

The measured and recalculated data, including data on the corresponding radial force load of the tested roller, are presented in Table 4.

Tab. 4 *Measured data one-day durability test*

Time [hod]	Tractive force [N]		
	20°C	40°C	60°C
1	39.5	39.4	55.0
2	39.5	39.3	55.3
3	40.5	39.5	55.6
4	40.0	39.3	54.7
5	40.3	39.3	54.5
6	39.5	39.6	54.2
7	40.5	39.3	55.7
8	39.7	39.1	55.1
9	40.0	39.3	55.5
10	40.1	39.4	54.2
11	39.9	39.0	55.0
12	40.5	39.4	55.5
13	39.9	39.3	54.2
14	40.4	39.0	55.0
15	39.6	39.5	55.6
16	39.6	39.6	55.0
17	39.6	39.1	55.0
18	39.8	39.4	54.2
19	40.3	39.2	55.1
20	40.3	39.4	55.7
21	40.3	39.4	54.4
22	39.7	39.2	55.3
23	39.7	39.3	54.8
24	40.5	39.2	55.4

An illustrative idea of the impact of different temperatures for the selected load level (400 N) can be obtained from Graph 3. It can be seen that at a temperature of 20 ° C the tested roller shows slightly higher resistances. However, it is important that at the highest temperature tested, the properties of the roller that define the value of the monitored tensile force do not change during the test period.



Graph 3 *Influence of temperature on the resistance (tensile) force of the roller for the selected load*

4.4 Weekly accelerated durability test

This measurement was performed to determine the stability of the properties of the tested roller for a load of 400 kg at a temperature of 60 ° C for 7 days without a break in the continuous load according to the following protocol:

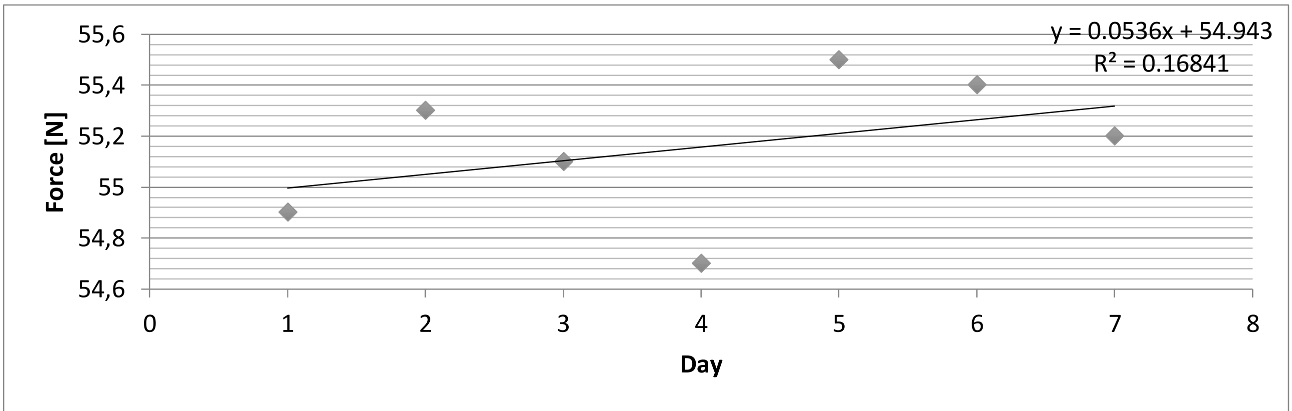
- Tested temperatures: 60 ° C
- Tested loads: 400 kg
- Drive roll speed: 187 1.min^{-1} (maximum value of the drive roll speed for the nominal working speed of the used electric motor at a frequency of 50 Hz
- The load values presented below are arithmetic averages of the values recorded in hourly intervals

Tab. 5 *Measured data one-day durability test*

Day	1	2	3	4	5	6	7
Tractive force [N]*	54.9	55.3	55.1	54.7	55.5	55.4	55.2

Measured and recalculated data, including data on the corresponding radial force load of the tested roller are given in Table 5. An illustrative idea of the output of this test can be obtained from Graph 4. The test was carried out for a load of 400 kg at a temperature of 60° C at the maximum achievable speed to induce extreme working conditions to improve the estimation of the real operating characteristics of the rollers used in the sampler.

The graph shows a fluctuation around the fourth day of testing. The reason for this is most likely a momentary failure of the regulation of the operation of the hot air gun. However, at the same time, it must be stated that the total fluctuation of the monitored tensile force occurs within about 1 N. Due to the value of the tensile force of about 55 N, this is a practically negligible effect. After passing 1 884 960 revolutions under very unfavorable operating conditions, the tested roller did not show a change in properties that led to a change in the resistance effects or to the failure of any of its components. Dimensionally, the tested roller also remained stable.



Graph 4 *Long-term effect of temperature for the selected load*

5 Conclusions

Based on the above experiment, it can be stated that the choice of travel rollers can be recommended for this purpose. Roller failure due to the applied load cannot be expected in a short period of time when using the sampler. Unfortunately, the rollers are certainly components subject to wear that were not directly monitored in this experiment. On the basis of the experiment, it can be estimated that the life of the rollers will be acceptable (8 hours of sampler operation corresponds to about 11 000 revolutions of the column extension rollers). This is about 170 operating days at the tested speed, after which no significant wear is expected.

The experiment pointed out the importance of respecting the operating conditions, especially temperature, when choosing rollers and dimensioning the related drive unit. However, this data is not available in commonly available materials from manufacturers (for obvious reasons - rollers are not primarily intended for such environments). It should be noted that the rollers are certainly components subject to wear, which was not directly observed in this experiment.

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