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GRIPPER WITH ADJUSTABLE GRIP FORCE

EFEKTOR S NASTAVITELNOU SILOU ÚCHOPU

Abstract

The article concerns itself with a gripper, which was made primarily by Rapid Prototyping technology (RP). The gripper has been designed and constructed on the Department of Robotics in the SGS project "GRIPPERS FOR MOBILE ROBOTS" under registration number SP-201071. In the article is documented the robot design particularly in terms of functional parts. An important chapter is a methodology of the gripper testing, where gripper parameters and its functional parts made by the RP technology were verified. In the final chapter are presented conclusions on the utilization of 3D printing for functional prototype components.

Abstract

Článek se zabývá efektorem, který byl vyroben převážně technologií Rapid prototyping (dále RP). Efektor byl navržen a zkonstruován na Katedře robototechniky V rámci projektu SGS „EFEKTORY PRO MOBILNÍ ROBOTY" S evidenčním číslem SP-201071. V článku je zdokumentována konstrukce robotu zejména Z hlediska funkčních částí. Důležitou kapitolou je metodika testování efektoru, kde byly ověřovány parametry efektoru a jeho funkční části vyrobené výše zmíněnou technologií. V závěru jsou pak uvedeny učiněné závěry ohledně využitelnosti 3D-tisku na funkční prototypové součásti.

1 INTRODUCTION

Grippers are functional mechanisms of service robots that perform work for which the whole robot was designed. The gripper is from this point of view a very important part in the service robot construction which cannot be neglected. In the case of service robots the grippers are very specific devices, which are made in small amounts. This leads to efforts to find ways to reduce overall costs of the proposed prototype testing and the subsequent production. In this case, the RP technology appears appropriate, since it allows fast parts production, their verification and also offers the possibility to use some parts made this way in the final product, especially in small series.

The gripper can be used as part of the manipulation subsystem in the mobile robot ARES developed by the Department of Robotics.

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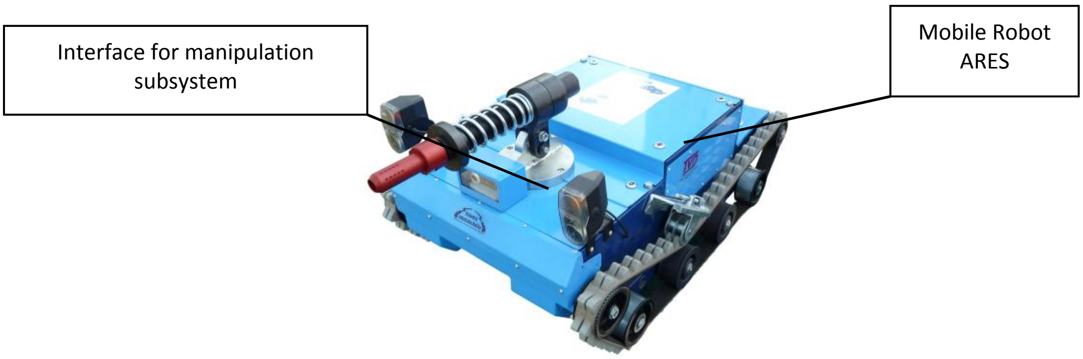


Fig. 1 Mobile robot ARES.

2 DESIGN OF GRIPPER

The main design concern was the use of the new manufacture technology, which was one of the requirements and with which there have been not enough experiences yet. Other input parameters of the design were the requirements on the applicability of the gripper on the mobile robot ARES, from which arose the requirements on the connection dimensions, the maximum permitted weight of gripper, the gripper drive energy options and on the bearing gripper capacity.

The fundamental requirement is the ability to maintain the object of manipulation (the OM) in the jaws in case of a sudden power outage during the motion of manipulating robot extensions. This condition corresponds to a relatively high gripping force relative to the expected weight of the manipulated object.

Tab. 1 – Gripper technical parameters

Payload	3 kg
Weight of the gripper	2.2 kg
Range of jaws	0/100 mm
Max. length of gripper with arm	912 mm
Length of gripper (without arm)	176 mm
Max. width	182 mm
Height	70 mm
Nominal voltage	24 V DC

The base construction consists of an aluminum tube, which is basically the end arm of the manipulator with a diameter of 40 mm and wall thickness of 2 mm. On the end of the tube are the connecting dimensions for the mounting to the manipulation subsystem of MR and on the other end is the gripper itself. The tube together with a flange for a drive unit mounting and a thread plate are the only parts that were not made by the RP technology. The conjunction of the tube with the gripper ensures an interpiece in which the drive of the gripper jaws is hidden. In the tube is an insertion in which threads were cut to join the tube via the screw connection. The output of a gearbox is fitted with a pinion, which transmits a torque to gear racks of each jaw, where the torque is transformed into a grip force. a pinion shaft rotates in pressed plain bearings IGUS. a linear movement of the jaws is ensured by two linear rails made by the company THK. Special features are locks, which allow a quick and easy replacement of the gripper jaws. Their application also verified the possibility of joining larger printed parts, which owning to their size exceed a print area of the printer.

Almost all components including the gear rack and pinion were made by the RP technology without any additional machining [1]. Exceptions that cannot be made by the RP technology are the threads in the insertion as well as finishing of the hole for the pressed plane bearings with a toleration H7 desired by the manufacturer and also additional machining of pinion shaft circularity and cylindricity as the deviation of 0.1 mm has occurred along the length of the shaft during the printing.

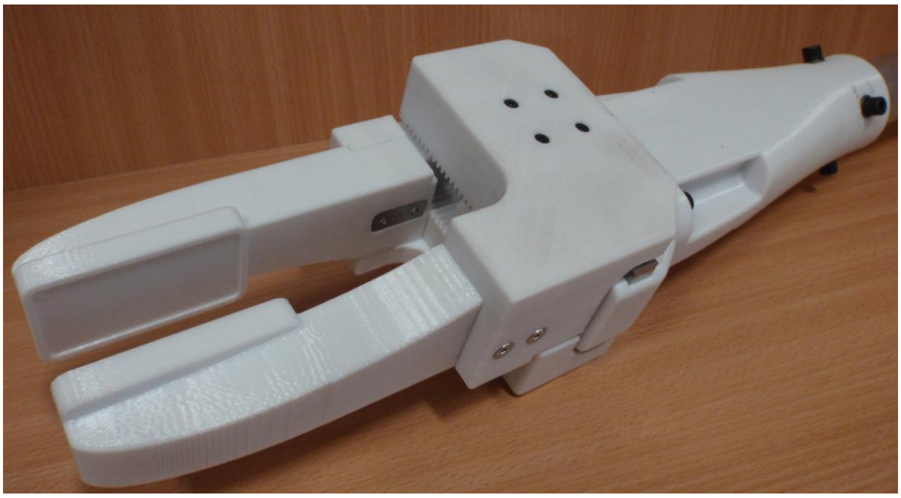


Fig. 3. Gripper.

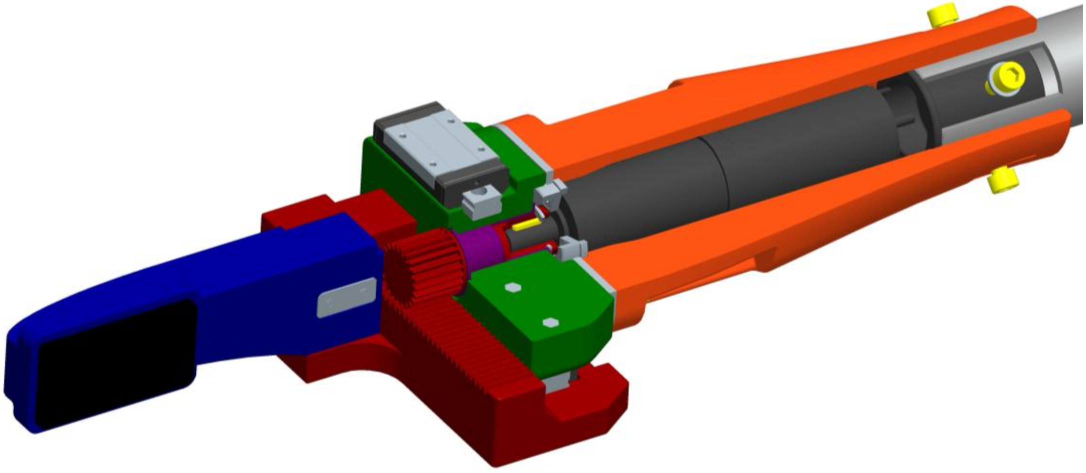


Fig. 4.Cross section of the gripper design.

Actuators of the gripper jaws are the DC **MOTOR RE-35 90W** [5] and the **PLANETARY GEARHEAD GP-32 HP** [5] made by the company MAXON Motor.

Tab. 2 – Drive unit technical parameters.

Weight of the drive unit	0.34 kg
Nominal output torque	93.3 mNm
Output RPM	6910 rev/min
Power	90 W
Nominal voltage	24 V DC

Tab.3 – Gearhead unit technical parameters.

Weight of the gearhead unit	0.249 kg
Max. continuous torque	8 Nm
Gear ratio	246:1

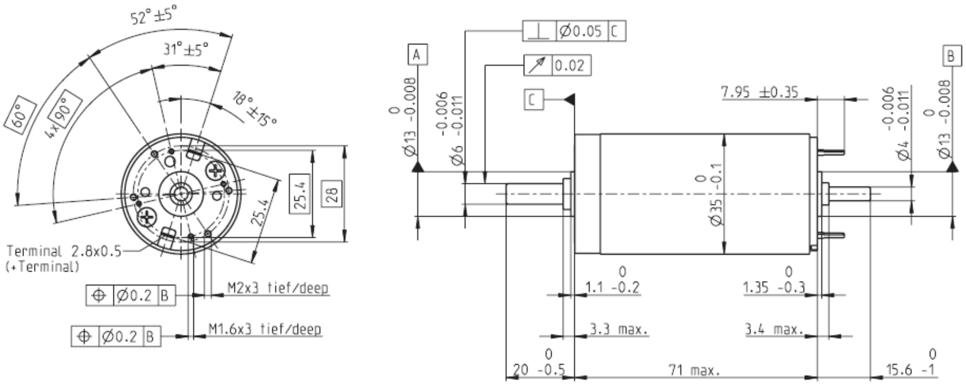


Fig. 5. Motor Maxon RE-35 90W (323890) [5].

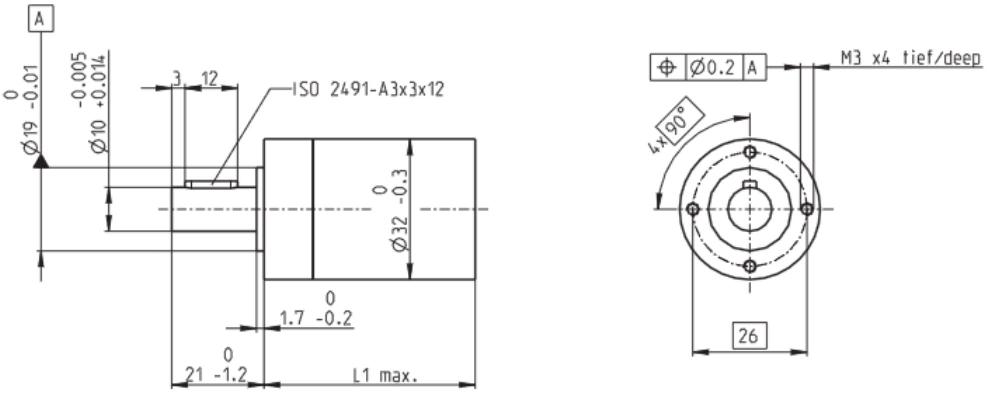


Fig. 6. Planetary gearhead Maxon GP-32 HP (324942) [5].

3 ANALYTICAL DETERMINATION FORCE OF GRIPPER

Firstly it was necessary to determine whether the designed actuators and consequently the mechanism achieve the required grip force. Thus an analytic method [2] was chosen in order to determine the total grip force.

$$l = \frac{\varnothing}{2} = \frac{0.02175}{2} = 0.011m \tag{1}$$

where:

l – arm (a radius of a mean diameter of the pinion) $[\mathrm{m}]$,

$ø$ – a mean diameter of the pinion $[\mathrm{m}]$.

$$M_{KP} = M_{KM} \times i \times \eta = 0.0933 \times 246 \times 0.6 = 13.771\, N.m \tag{2}$$

where:

M_{KP} – torque at the output of the gear unit $[N.m]$,

M_{KM} – maximum torque at the output of the engine $[N.m]$,

i – gear ratio $[\text{-}]$,

η – efficiency of gearbox $[-]$.

$$F = \frac{M_{KP}}{l \times p} = \frac{13.771}{0.011 \times 2} = 633\, N \tag{3}$$

where:

F – grip force of the gripper $[N.m]$,

M_{KP} – torque at the output of the gear unit $[N.m]$,

l – arm (a radius of a mean diameter of the pinion) $[\mathrm{m}]$,

p – number of the jaws $[-]$.

The gripper mechanism was also subjected to the simulation in the software Pro/ENGINEER (hereinafter ProE). All relations of the gripper jaws mechanism were introduced into the module mechanism of the ProE and by the conducted analysis the grip force of the gripper has been ascertained [3].

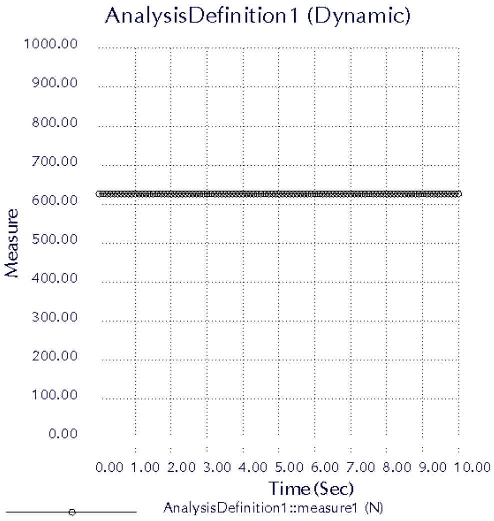


Fig. 7 Graph of the gripper power in ProE.

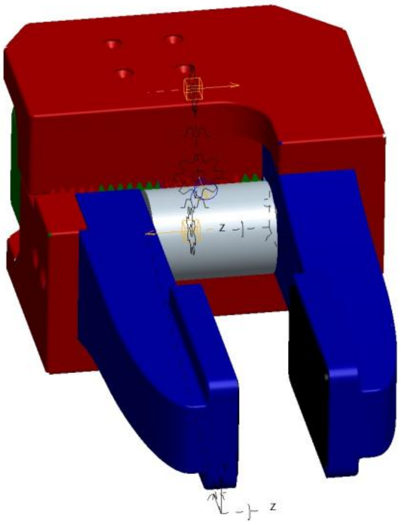


Fig. 8 Gripper in modul mechanism.

The calculated force is consistent with the analysis carried out in ProE. It follows that the theoretical gripper grip force is 633N.

The ability to hold the OM depends not only on the grip gripper force but also on the shape of the object and the coefficient of a friction between rubber stickers of the gripper jaws and the OM. Given that these coefficients vary depending on the material of OM they are not taken into the account as the purpose of the analysis is to determine the force derived from the actuator and the gripper mechanism and to verify the functionality of the RP technology.

4 EXPERIMENTAL DETERMINATION OF FORCE OF GRIPPER

The grip force measurements were conducted using a miniature load cell (type **LCM304-5kN**) [6], which is able to measure the force up to 5000 N with an accuracy of 0.5 %. The load cell was inserted between the gripper jaws and the performance pulse of the PWM motor control was gradually increased that led to the current input increase of the drive unit and by the use of simple application created in SW Visual Basic it led to the increase of the torque at the gear output by which the jaw force applied on the load cell was increasing. The load cell was placed between the beginnings of the jaws because of the jaw structure deflection which could occur with the increasing acting force and could negatively influence the measured values.

Fig. 9 Miniature Load Cell LCM304-5KN [6].

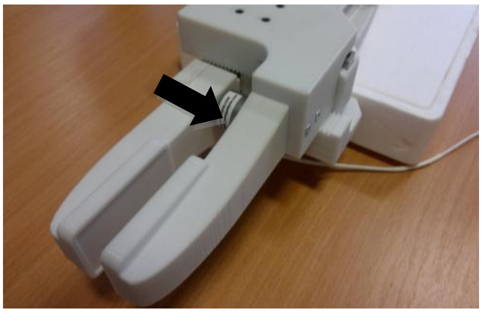


Fig. 10 Position of Miniature Load Cell in gripper.

The load cell **LCM304 5kN** is a strain bridge connected to A/D converter with the output on the bus RS485, which is transferred by the transmitter **RS458/USB** into PC. The load cell has an initial deviation of 2% and this is compensated by the A/D converter [4].

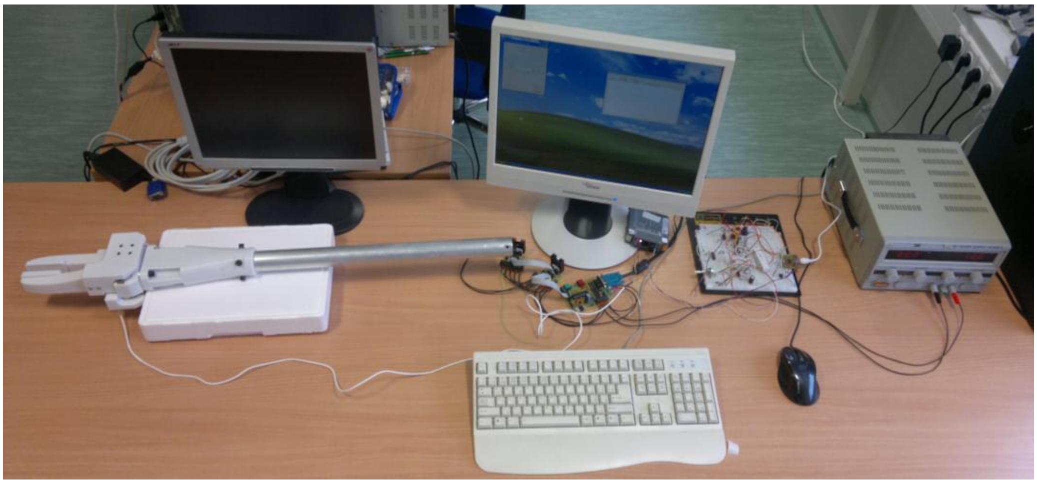


Fig. 11 Experimental determination force of gripper.

The motor is actuated by an H-bridge which receives the information about the direction of the rotation and the PWM signal that determines the torque given out by motor. These data are processed by a microcontroller, which receives the data via the bus RS232 from the control PC.

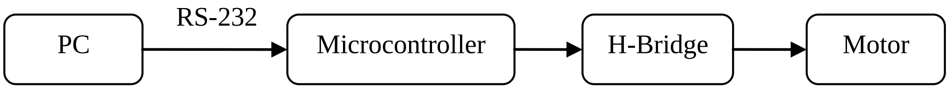


Fig. 12 Diagram of electronics.

The electronics design is divided into two sections: control and power. The control section contains a microprocessor and a 5V stabilized power supply a control logic. The power section contains the H-bridges, which are divided due to their modularity. It is possible to bus-interconnect multiple modules to improve the performance. This concept was chosen because of the limited current flow in one circuit – 2 A.

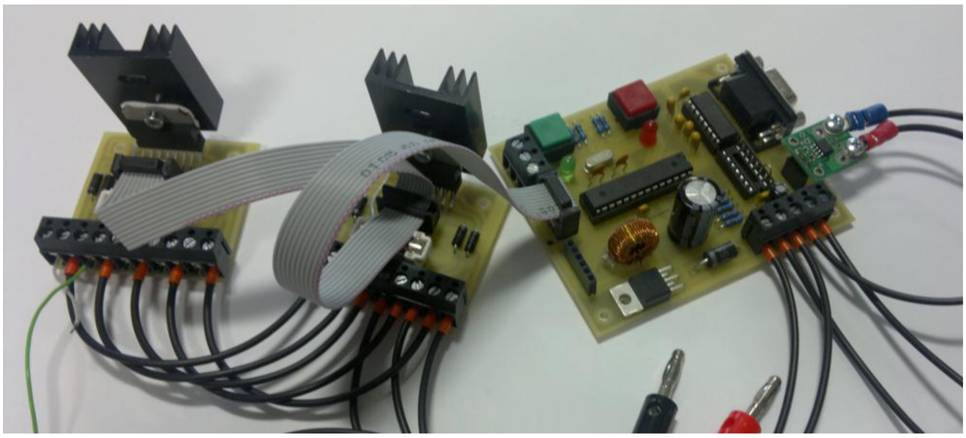
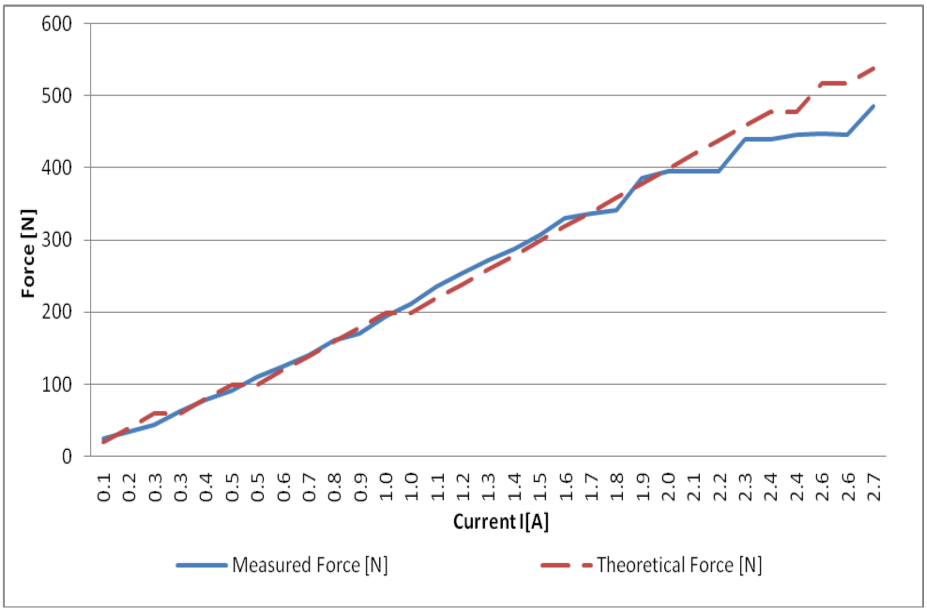


Fig. 13. The control circuit.

The current values were read from the power supply. Readings from the load cell were after a calibration transposed into the force F_M [N]. a graph of the grip gripper force dependency on the current was obtained by entering the readings in a table. The magnitude of grip force was compared with a theoretical power F_T [N] calculated on the base of the proportion of the torque on the current given by the manufacturer.



Graph 1. The grip force dependency on the current magnitude.

Calculation of the theoretical force F_T[N]

$$M_{KMT} = T_C \times l \tag{4}$$

T_c – constant torque of the motor, $\left[\frac{N.m}{A}\right]$,

M_{KMT} – theoretical torque at the motor output, $\left[N.m\right]$,

I – current flowing through the motor, A.

The result figure of the theoretical force F_T [N] is calculated into the equation (3).

The maximum current magnitude introduced in the drive is $I = 3.3$ A. At this current the gripper should have the maximal grip force $F = 633$ N. This force exceeds the level of force at nominal (exceeded at $I = 1.9$ A) and also permitted short-term torque of the gear output. During the measurements a possibility of short-term drive overload was verified up to the input current level of $I = 2.7$ a at which the maximal grip force $F_M = 486$ N was measured. This maximal grip force exceeds the maximal force at nominal torque of the gear output by 35 %.

The graph shows that the grip force increases almost linearly up to the current level of $I = 1.6$ A, after this level the force increases in jumps which is caused by passive resistances. In order to verify the correct measurement procedure and measured data the force figures were calculated in MS Excel from the measured data up to the current level of $I = 3.3$ A. These figures were compared with the calculated maximal theoretical force F.

Tab. 4. Measured data.

No M.	Force F_M [N]	Current I [A]	No M.	Force F_M [N]	Current I [A]	No M.	Force F_M [N]	Current I [A]	No M.	Force F_M [N]	Current I [A]
1.	25	0.1	**11.**	171	0.9	**21.**	341	1.8	**31.**	486	2.7
2.	34	0.2	**12.**	194	1.0	**22.**	386	1.9	CALCULATED FIGURES		
3.	44	0.3	**13.**	212	1.0	**23.**	395	2.0			
4.	63	0.3	**14.**	235	1.1	**24.**	395	2.1	**32.**	518	2.8
5.	78	0.4	**15.**	254	1.2	**25.**	395	2.2	**33.**	534	2.9
6.	91	0.5	**16.**	271	1.3	**26.**	440	2.3	**34.**	550	3.0
7.	110	0.5	**17.**	287	1.4	**27.**	440	2.4	**35.**	566	3.0
8.	125	0.6	**18.**	306	1.5	**28.**	445	2.4	**36.**	582	3.1
9.	141	0.7	**19.**	330	1.6	**29.**	448	2.6	**37.**	598	3.2
10.	161	0.8	**20.**	336	1.7	**30.**	446	2.6	**38.**	614	3.3

The accuracy of the measurements can be verified by comparing the calculated grip force F with the measured grip force $\boldsymbol{F_M}$.

The maximal difference between **F** (3) and $\boldsymbol{F_M}$ is 19 N. This difference could be caused by the calculation of the figures on the base of the previous data. As it is evident the calculated figures do not increase the force in jumps, the losses in the bearings and linear rails and also other factors may affect the measuring instruments accuracy, which can make 25 N in range of 5000 N and with deviation of 0.5 %.

6 CONCLUSION

According to the requirements the two-finger parallel gripper with adjustable grip force has been designed. The gripper payload is 3 kg and the jaws range is from 0 to 100 mm. The gripper mass including the arm is 2.2 kg, without the arm is 1.68 kg and without the arm and the drive the gripper mechanism weighs 1.091 kg. The gripper has been designed from the maximum amount of pieces made by the rapid prototyping technology.

By the calculation and the following verifying measurements the maximal theoretical grip gripper force 633 N has been determined. This force is not utilized with this type of gripper design and technology because the maximal short-term torque at the gear head output is only 12 Nm which is equal to the force of 551 N. It is advisable according to the gear head lifespan to keep the continual torque at 8 Nm which is equal to the force of 363 N. The grip gripper force is necessary to electronically limit to this level of force. Otherwise, the long-term use of higher force would make an irreversible damage to the gear. During the testing the advised torque level was exceeded and the highest achieved and measured grip force was 486 N which corresponds to the torque at the gear head output of 10.7 Nm.

The rapid prototyping technology has demonstrated its capabilities and capacities on the functional prototype part of the gripper design. The required grip force in the jaws at nominal torque has been achieved but also exceeded by 34 %. The ratio of price/speed/grip force/gripper mass/maximal MO mass is very favourable and the RP technology will be probably deployed in the future not only in the gripper construction but also in other devices.

A very positive finding was that it was not necessary to machine the pinion and the gear rack and that they performed their functions well. After the conduced tests there were no cracks in their construction even though they were highly stressed components. The grip force of 363 N is for the expected object mass of manipulation of 3 kg more than sufficient.

As a next recommended step is to test the grip force on the OM in the dynamic tests in which the manipulation subsystem should be sharply stopped during its operation. In this experiment there could be used the conclusions from a use of higher grip force not only from the nominal torque figures. This type of test has not been possible as the final work on the gripper arm has been undertaken.

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